# Air Repair

Typical Smog Cloud Over Los Angeles. Mountains behind city hem in air masses. (See Littman and Magill, Page 29.)

**AIR POLLUTION CONTROL ASSOCIATION**

**4400 FIFTH AVENUE** **PITTSBURGH 13, PA.**

**FOUNDED 1907**

# Air Repair

A QUARTERLY JOURNAL DEVOTED TO AIR PURIFICATION



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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of these opinions.


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# New Officers For 1953-54

THOMAS C. WURTS, *President*

Director of the Allegheny County Bureau of Smoke Control, Pittsburgh, Pa. Cornell University graduate in mechanical engineering. Served Westinghouse Electric Corporation in engineering and sales, and was promoted to manager of heavy traction sales before setting up his own office as consulting engineer. He has headed the Allegheny County Smoke Control Bureau ever since its inception in 1947.

# New Directors

HARRY C. BALLMAN

*Harry C. Ballman, who filled a board vacancy in 1951, is Smoke Regulation Engineer of Columbus, O. An alumnus of the University of Cincinnati, he was active in industrial sales work, but since 1947 he has been an air pollution control official in Indianapolis, Ind., Richmond, Va., and Columbus, O.*

R. LIVINGSTON IRELAND

*Mr. Ireland, President of the M. A. Hanna Coal Company, is also chairman of the Executive Committee of the Pittsburgh Consolidation Coal Company and resides in Cleveland. His present business affiliations include directorships in the National Steel Corporation, the Phelps Dodge Corporation, the Union Bank of Commerce, Cleveland, and the National Coal Association.*

RALPH W. BOURNE

*This University of Pittsburgh chemical engineering graduate is Chief of the Air Pollution Control Engineers of Jefferson County Air Pollution Control District, Louisville, Ky. His industrial experience includes tours of duty spent with du Pont, Reynolds Metals, and the Louisville Soy Products Company. He has been a municipal air pollution control official in Louisville since 1947.*

HERBERT L. WAGNER

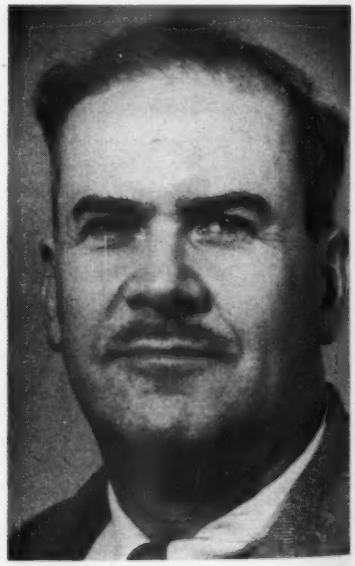
*Herbert L. Wagner was named Vice President in Charge of Engineering of the Detroit Stoker Company four years ago. He received his technical training at Valparaiso University, Valparaiso, Ind. He has been with his present firm for 18 years. Before that he was associated with the Whiting Corporation and the Studebaker Corporation.*

MILLER G. STEWART

*It was in 1912 when Miller G. Stewart began to work for the Pennsylvania Railroad. He has been in railroad work ever since, and was promoted to his present position—road foreman of engines—in 1941.*

JOHN E. BROWN

*The Air Pollution Control Engineer of the Department of Smoke Regulation, County of Milwaukee, Wis., obtained a degree in mechanical engineering from the University of Cincinnati, followed by postgraduate work at Columbia. He served on a number of APCA committees.*



## ANNUAL MEETING PAPERS

For many years the Air Pollution Control Association has published its annual proceedings in book form. This year the Board of Directors decided to hurry publication by printing the papers given at the Annual Meeting in serial form in *Air Repair*, then binding a number of copies at the conclusion of the fiscal year and offering them to the members at a modest figure—just enough to cover printing and handling costs. This was announced in the June-July issue of *Apca News*, and quite a few members have already responded, asking that a bound copy of the Proceedings be reserved for them. If authors wish to have reprints of their papers, printing can be arranged by filing requests with Headquarters, which will advise as to cost for the number of reprints desired.

# Free Enterprise and Air Pollution Control

*by* STANLEY STOKES
Vice-President, Union Electric Company of Missouri
St. Louis, Missouri

"There ought to be a law! Somebody ought to do something about it!" exclaims the man on the street whenever he is inconvenienced by air pollution. There are a lot of these men on the streets and when these inconveniences and discomforts continue they talk to each other and to the newspapers, and they write articles. Public opinion is an illusive thing, but the number of column inches in newspapers is a good indication of the trend. This publicity has been gradually increasing in recent years, but lately I note that air pollution is attaining honorable mention in a different type of publication such as "News Week".

This increase in public interest in air pollution is keeping pace with the increase in the density of urban population. The population increase in America during the past year is more than equivalent to three cities the size of Baltimore and next year it will equal about four such cities. Accompanying this increased rate of population growth we have the transfer of people from rural communities to the cities. For example, adjacent to our territory in Iowa, in the decade 1940 to 1950, the population of Appanoose County declined 18.9%, Lucas 17.2%, Keokuk 9.0%, Decatur 10.5%, Wayne 12.0% and Ringgold 14.4%. With the advent of modern mechanized farming there is no need for so many people on the farm, and they drift into the smaller towns and from there to the large cities.

At the moment in St. Louis, the man on the street is particularly perturbed by an increasing traffic problem, which also worries the downtown business man as well, and there again, he probably says, "There ought to be a law!" Well, in this case there are lots of laws, ordinances, rules and regulations, and still the traffic gets worse and worse. With narrow streets radiating into a hub like the spokes of a wheel, and with the population many times that for which these streets were originally designed, it is evident that it requires more than new rules and regulations to solve the traffic problem.

What concerns the business man is that the problem is solving itself by the migration to the surrounding country side and the resulting stagnation in the downtown business district. With increasing population and increasing production per capita, and with both industry and the population trying to get into the large metropolitan centers, we have problems in air pollution, stream pollution, traffic, transportation, housing, and organized crime. Since all of these problems were caused by the tremendous concentration of population in a few large centers it seems that the reverse operation or decentralization would solve many of them. This may be, and probably is, one of the real methods of approach for a long range solution of the air pollution problems.

It was recently announced that architect Frank Lloyd Wright would receive a medal from the National Institute of Arts and Letters. When interviewed he talked about the present trend toward decentralization. The city, he said, is a hang-over from feudal times. Once it was necessary, but it has reached and passed its peak and soon you will see it disappear.

Those who own businesses and property in the city are trying to find ways to prevent this emigration, whereas from the viewpoint of one who has no investment in the city, and who looks at it from a distance, perhaps it is a natural and proper trend. If one wishes to aid and abet this movement he could readily do so by increasing taxes in the city and correspondingly provide tax exempt premiums for locations outside. If such a transition were made over one or two generations probably everyone would be better off. However, if I happen to be one of those enthusiastic "do gooders" and desire to cure the problem over night, and am successful in obtaining a drastic law which doubles taxes in the city and halves them outside, I create havoc, fail to accomplish my purpose and wind up having the law repealed.

What is to be avoided in air pollution control is not legislation, rules and regulations as such, but ill-advised precipitous action without understanding the problem and in the absence of necessary facts to deal with it.

In considering uniform air pollution codes it may be that they should apply with almost as much stringency in open territory as they do in congested areas. Industry moves into the outskirts or suburban territory and in a few years it becomes densely populated; and then we have existing investment in inadequate facilities which can hardly be legislated out of existence, and yet should not be tolerated because they are a nuisance under the new conditions.

If we look at this thing as an over all picture, it seems to be a sound conclusion that one of the proper and necessary costs of producing manufactured products is the cost of maintaining adequate air pollution control. If this economic burden were distributed over all industries and in all locations, then the requirement for one factory to spend substantial sums on smoke abatement would not permit a competitor located at some distance away, but who wouldn't have to contribute toward smoke control, from cutting under his production costs.

Uniform air pollution codes, developed under the guidance of your Air Pollution Control Association with the assistance of the engineering societies, and advice from leaders in their particular fields, are gradually adopted throughout the country. These uniform codes should probably contemplate local enforcement by the city and county. The state can be of assistance in cooperating to obtain uniform regulations and perhaps to maintain as part of their regular health department, someone specializing in air pollution to give assistance and advice to the smaller communities and the unincorporated areas in the counties.

Some folks in industry have indicated that they would prefer state control. It seems to me that the state would be a less efficient unit to police and enforce these regulations than either the city or the county, and that if uniform regulations existed in all states the desire on the part of some industrialists for state regulation would disappear. It is easy to see that large corporations having factories in a number of states would not want to operate under different rules and regulations and with different equipment in each state and hence might prefer state regulation on the theory that they would thereby be more likely to have uniform codes. If the codes were already uniform I believe this demand would not exist.

The greatest present need is in clarifying conceptions as to the nature of the air pollution problem in a particular area and the requirements for improvement. Where the finger is pointed at industry, it has the right to require proof that its operations are in fact contributing significantly to the air pollution condition. No local investigation nor survey is adequate unless it undertakes to answer the following questions, and the tools for their elucidation are now available.

(1) What is the nature of the air pollution nuisances in a particular area?
a—dust fall?
b—coal smoke?
c—gas effects ($SO_2$, $H_2S$, F)?
d—miscellaneous odors?
e—demonstrable health effects?

(2) What are the particular sources and what is their relative contribution?

(3) What is involved (engineering-wise) and economically, in the abatement of major sources?

(4) What form of ordinance or regulation is practical and equitable to accomplish the improvements indicated by this analysis?

Industry will be well advised not only to collaborate in a technical investigation of the nature described above, but, further, actively to promote such undertakings. Indeed, it has frequently demonstrated willingness to contribute financially or even to take the lead in promoting such projects. Industry should, however, realize that even though it does undertake the total financial and technical responsibility for such a study, it is not justified in excluding competent representatives of the public from sharing in the knowledge of the findings. Indeed, it is important, if full benefit to the community as well as to industry is to be derived from such an undertaking, that it be a joint one between industry and the local government.

More and more industry is recognizing the major important duty of collaboration with society through its local government units. The power industry is a particularly apt example, not only of the desirability, but of the necessity to earn the good will of the people in the community it serves, who, after all, are its customers and who through its public utility regulatory agencies control in large measure its stockholder dividends.

While unfortunately it is not generally realized, the fact is that for many years the power industry has been in the forefront of technical activity toward improvement in air pollution control.

Upon completion of the present dust collection program Union Electric Company of Missouri will have more than four million invested in air pollution control equipment for protection of the St. Louis area, and utilities in other cities have equivalent amounts. This equipment operates in most cases above the accepted standards.

Few people realize the discouragement of power company officials and engineers when unjustified criticism is leveled at them after years of costly programs pointed towards improvements in ash and smoke control.

In general I believe that satisfactory technical solutions exist to the problem of eliminating flyash and solids from flue gas but there remains the fundamental requirement of finding ways to do it at lower cost. I am sure that such possibilities exist. For example, there have been three or four instances in which large size agglomerated particles came out of our Cottrell dust collectors at Venice Power Plant and fell down around the station building like snow. These instances occurred during humid weather conditions with low hanging clouds, and when using steam soot blowers. By some combination which we cannot reproduce at

will these dust particles agglomerated. If we could do this under controlled conditions, we could throw out those large particles with a simple mechanical separator and might be able to eliminate a large portion of our Cottrell plan. The cost of collecting equipment can become acute in the case of the small industrial plant.

The other phase in which industry is interested as well as the public is the emission of quantities of gas containing some carbon monoxide, sulfur dioxide, hydrogen sulfide or other objectionable gases. The automobile, the bus and the truck are in this category. Here it seems to me some additional study is necessary and should be undertaken by industry as a whole to find ways to further abate this annoyance. Such research to accomplish much would have to be more or less continuous. To assure continuity, funds should be authorized at least five years in advance.

Although everyone would benefit by the results of such work it is rather difficult to finance this type of undertaking because no particular firms or individuals feel that they are largely responsible. If free enterprise wants to continue to handle the problem of air pollution the best protection it can have would be to maintain a continuous study of the problem and obtain all possible facts. If an effective and adequate program is under way, there is little to justify its duplication by government at taxpayers expense. The bituminous coal industry carries on research and pays for it by levying a penny or fraction thereof on each ton of coal produced. If there were a way by which a microscopic fee based on gross sales could be collected this would be more than adequate to accomplish the purpose. It may be that this contribution should not necessarily be limited entirely to those industries responsible for causing air pollution. All industry as well as the public are beneficiaries of any progress that is made. Again, if free enterprise does not actively carry on this work it leaves an opening to those who advocate government in business, to press their case.

There is no lack of competent organizations to do this work such as the Industrial Hygiene Foundation of America, or right here in Baltimore you have Johns Hopkins, and there are many other adequate groups that could share in this undertaking. At the moment there is a shortage of trained men for such work, but that condition is temporary.

I am not going to argue that government cannot carry on research, or operate public power—they are doing it. In the field of public health they have done a good job for many years. In the atomic field in which at present they have a monopoly, they are spending huge sums—such as 16 million a year financing atomic physics research. In this case the work itself is largely carried on in universities, or under the direction of private corporations or laboratories.

The question is not whether the government *can* do these things but whether it *should*. When the government generates electric power they use the same machinery and the same methods that are used by private power companies, but the incentive for economy, efficiency and prudent investment are not the same. When one is spending his own money he is likely to be both careful and prudent.

When the government finances research, even though carried out by private enterprise, it remains in control and control gets involved in politics. At the moment the operation of the atomic program is in the hands of men who are believers in private enterprise and they have channeled their work insofar as possible through private corporations. However they themselves recognize the inherent danger in this kind of public monopoly. Changes in atomic legislation are being considered at this time.

By and large, air pollution is not a problem of health in this country. If abatement is systematically carried on it will never become one. This statement is generally accepted by those familiar with the subject and who are also aware of the circumstances surrounding the Donora incident. It does however exclude dense coal smoke (e.g. London 1952). There is today little reason for such a condition to ever exist here. Industry has eliminated dense coal smoke years ago and the cities have that phase under control.

Air pollution is a wide-spread nuisance affecting millions of people and as such everything possible should be done to eliminate it.

Positive action in this direction will prevent it becoming a health problem, and this to me is a potent argument against ill-considered research on the health aspects. I am not opposed to the latter but would insist on adequate scientific basis for their initiation.

To say the least it seems unnecessary to devote large sums of research money trying to develop evidence that air pollutants may be injurious when everyone is already in favor of its abatement as a nuisance.

My assignment was presumably to devise and present a solution to the problems facing free enterprise and those of air pollution control and do it in 25 minutes. I may attempt to do this "in just a moment" as they say on television when they stop for advertising. In the meantime I wish to tell you about a busy executive who was accustomed to making addresses with the speeches being written by a ghost writer. In this instance he was to talk about the international situation and as usual called in the ghost writer to prepare the speech. He told the writer to start back with World War II and the Yalta Conference and gradually work up to the situation in which we now find ourselves, and then go on from there with an outline of what ought to be done. The ghost writer, who had become increasingly discouraged over writing things for other people, and who was dissatisfied with his salary, went to work on the speech, and when the executive took off in his plane for the meeting, he glanced over a few pages. It seemed to be exactly the type of thing he wanted, and he went to the banquet with a feeling of confidence. At the meeting he proceeded to

read the speech and the more he read the better it got. On page 12 he reached the point where a solution of the problem was to be presented but as he turned the page, the next sheet was blank except for one line reading: "Now, you old rascal, you are on your own."

You are specialists in the field of air pollution and know that no "miracle" is likely to provide a ready solution.

Your organization is proceeding along sound lines and is certain to accomplish a great deal of good. Industry as a whole is doing itself a real service when it takes an active part in your activities, and incidentally helps to defray some of the cost.

The following suggestions are offered for what they may be worth.

*Short Range Approach—How You Can Help*

Hold the line on air pollution control in spite of probable necessity for stringent economy in the operation of our cities for the next few years.

*How Industry Can Help*

Continue with its present dust collection program in spite of possible lower dividends and necessity for economy.

Provide a fund for further study of this problem. In order to solve a problem one must be able to state it. Nowhere can you find a complete overall adequate statement of the air pollution problem, broken down so that one can attack first things first. We should have a plan for each five-year period and these plans have to take a great many factors into account. This is an economic problem.

To produce such a statement is in itself a major undertaking and will cost some money. Industry would be well advised to provide these funds.

It is impracticable to delineate here all of the phases into which such a study should be subdivided. Each of you here can mention a few and the combined technical resources of industry can readily cover the field.

Probably the most important matter at the moment is the uniform code development and the zoning laws. In suburban areas near a large city what is farmland today becomes densely populated urban territory within one generation. If we stop producing air pollution nuisances in new territory we won't have to do things all over again a few years later.

*Long Range Approach*

Since the problems of air pollution, city planning, stream pollution, traffic, transportation, housing, slums and organized crime are all a function of population density, would it not be sensible to have a representative from each organization interested in one of these phases, meet together periodically to develop plans by which de-centralization of population could, over a long term, be carried out so as to accomplish the desired results with minimum hardship.

Continue your efforts on a long range basis for steady improvement in uniform codes and zoning laws.

# Conducting Field Tests To Determine Dust Emissions From Stacks

*by* H. C. Johnson, Assistant Smoke Regulation Engineer, Columbus, Ohio

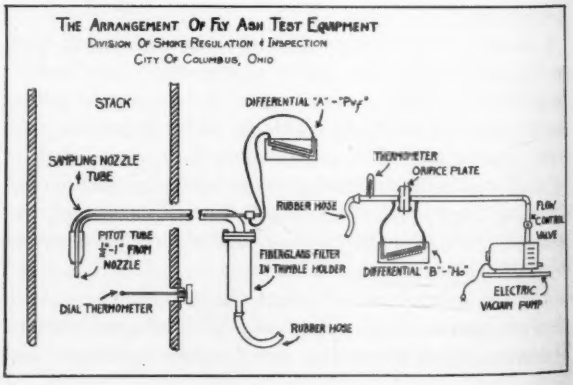
In spite of great advances in recent years in scientific methods of testing, no simple method has yet been discovered for determining the quantity of fly ash being emitted from stacks. ASME Power Test Code "Test Code for Dust Separating Apparatus"[1] remains the recognized authoritative source of information on fly ash testing, which we follow except for deviations explained in this paper. We hope this paper will be of practical value in supplementing the ASME Test Code, which should be thoroughly digested and used as a reference for conducting dust emission tests. Battelle Memorial Institute has contributed greatly in determining details of equipment and procedure necessary for fly ash tests.[2] Battelle recommends drawing a sample of 20-25 c.f.m.; the sample collected is adequate to run a size analysis on the stack effluent. The size and number of particles leaving the stack is valuable information. However, if an ordinance only stipulates weight per thousand pounds of flue gas or grains per cubic feet, the air pollution officer's primary interest is in the weight of emission.

We therefore feel that in selecting equipment the gas flow through the test equipment of 2-5 c.f.m. is satisfactory. This capacity greatly reduces the size and cost of test equipment. The requirements for test equipment we have found to be as follows:

1. Accuracy within plus or minus ten percent.
2. Relatively inexpensive.
3. Portable.
4. Flexible—can be utilized in any location.
5. Operation—by one or two men.

Our equipment preference is:

1. Pitot tube preferred for velocity measurement, since the pitot gives instantaneous reading for velocity.
2. Portable inclined manometer for measuring velocity determined by the pitot tube (an inclined "U"



tube), scales ranging from 0.02" to 0.1" $H_2O$ per inch on scale.

3. Stainless steel nozzle, pipe assembly (½") and filter bag holder.
4. Fiber glass filter bags—operates with low pressure loss and is not damaged by condensation.
5. ½" I.D. rubber hose connection between filter bag housing and orifice in vacuum pump assembly.
6. Electric vacuum pump for drawing sample—eliminates need for compressed air supply.
7. Orifice plate in straight section of pipe (calibrated with gas meter).
8. Draft gage to measure flow of gas sample through orifice, 3" to 4" $H_2O$.
9. Valve in pump suction line to regulate flow—cock or needle valve.
10. Mercury thermometer installed in a well upstream from the orifice, 0 to 200° F.
11. Dial thermometer with 18"-20" tube for insertion in stack—200 to 600° F.

A survey of the plant will establish the best location available for removing sample of flue gas. Normally the center of the longest straight section of a stack or breeching is preferred. We require the plant to install the openings in the stack or breeching and necessary scaffolding for running the test. The scaffolding must be erected securely with guard rails around the platform for safety of test personnel.

Two holes 90 degrees apart in the stack or breeching are required for round sections. Four to eight holes equally spaced are required for rectangular sections. Either 16 or 20 test points are sampled in traversing a round section; points are laid out as shown in the ASME Test Code. The number of points to be sampled in rectangular sections should be determined as suggested by the ASME Test Code. We have found a horizontal angle iron rail above the openings to be most convenient for supporting the probe unit. Chalk or paint marks on the rail can be used to indicate nozzle positions. A stable location for the inclined manometer is most important. On steel stacks a shelf can be welded directly to the stack for the inclined manometer.

The fuel to be available and in use during the test should be checked. If fuel from more than one source is to be normally used, the fuel with the highest percent of fines should be burned when the test is run. Run of the mine or unwashed coal can be expected to produce higher dust loading than washed or double-screened coal.

Plant operation should be sized up during the preliminary survey. Conditions as found should be maintained during the test so that the results will represent day-to-day emissions. Violating plants may be brought within the ordinance by improved operation. Any improvements dependent on the whims of the operators will require periodic checking to keep the stack emission within the legal limits.

Though we attempt to follow the ASME procedure there are some deviations which we have found to simplify the test and other deviations that sometimes are necessary:

1. Of necessity the best sampling location available seldom meets suggested requirements.
2. In the equation for differential across the measuring orifice (1), the correction for pressure drop from flue to orifice exit is neglected, which results in an error of 0.5 to 1% for 1 to 2 c.f.m. sampling rate.
3. The pitot tube location with relation to the nozzle as recommended by ASME has not always been strictly adhered to due to difficulties of getting the assembly into the stack. It has been our thinking that if the pitot tube is located so that the nozzle does not interfere with the velocity reading, that any deflection of gas flow by the pitot tube has to be neglected.

COLUMBUS CHART: A chart was developed by John Applegate, formerly Assistant Smoke Regulation Engineer at Columbus, to eliminate all field calculations. The orifice differential can be determined in about five seconds after moving to each test point. The value of orifice differential is corrected for stack temperature, orifice temperature and velocity. This chart also gives the weight of gas flow through the orifice. However, after determining the proper orifice coefficient (we used a gas meter) the ASME equations for orifice differential and weight of gas flow can be broken down into component parts which can be plotted on charts. We believe the time required to develop charts is well spent; trying to be accurate with a slide rule 50 feet up a stack is difficult and delays adjustment of nozzle velocity after moving to each test point.

DETAILS OF THE COLUMBUS TEST METHOD:

The fixed point method of testing is used. Nozzle velocity is maintained to equal the flue gas velocity at the sampling point. The pitot tube is securely fastened to the sampling line in a position parallel to the nozzle and extending beyond the nozzle about one inch.

TEST PROCEDURE:

1. Pre-assembly of test equipment. Our equipment is pre-assembled to save time on the job as follows:

Group I—nozzle, sampling pipe, filter bag housing and pitot tube.

Group II—vacuum pump, orifice, control valve, draft gage and thermometer (the latter 2 items may be installed on the job to prevent breakage).

Operation of all equipment should be checked before leaving for the job.

A check-off list assures having all needed equipment available.

2. Assembly of test equipment (after test equipment has been hoisted to test platform):

(a) Connect hose between orifice pipe and filter bag housing.

(b) Level inclined manometer and connect to the pitot tube with long rubber tubing so that all test points can be reached. Tubing must be secured so that no strain will occur on the manometer. Tubing should also be positioned so that test personnel will not step on tubing or trip on the tubing.

(c) Insert thermometer in stack through one of the unused test openings.

(d) Install filter bag and seal filter bag housing.

(e) Before installing nozzle in stack check operation of all equipment.

(f) Insert nozzle in stack.

(g) Install infiltration cover around the test opening in the stack.

3. Initial traverse:

(a) Should be run to establish that the nozzle size is proper for the velocities in the stack.

(b) Should be run to discover any reverse flow conditions. If reverse flows are found these test points cannot be used and additional time must be allotted to all other sampling points. This is necessary to give adequate sampling time.

4. The first test is run at normal plant load and conditions. This test gives a record of fly ash emissions at this operating point and also allows a shake-down run for equipment and personnel. The second test at maximum capacity can then be run after establishing that this rate can be maintained for the duration of the test. After calculating the results of tests one and two, a third test may prove desirable to check either of the first two tests.

5. Running the test:

(a) Boiler load should be stabilized one half to one hour before starting test.

(b) Insert nozzle at point one.

(c) From velocity and stack temperature, using ambient temperature for orifice temperature, find the orifice differential from chart.

(d) Record time, start the aspirator, and set orifice differential to the proper value. Record stack temperature, orifice temperature, velocity, pressure and orifice differential.

(e) When one half of the time at point one has elapsed, re-set the orifice differential for the actual orifice temperature.

(f) Be ready to move to point 2 15-20 seconds before time is up at point one. Start moving about five seconds before time is up and quickly read velocity at point two. From velocity at point two pick orifice differential from chart and re-set valve to give this value.

(g) Repeat procedure until testing is completed.

(h) At the end of test in each opening turn the nozzle up, stop the aspirator and remove nozzle from stack. Run the aspirator at maximum flow and tap nozzle to loosen any deposit.

(i) Repeat procedure for all points in each test opening.

(j) At the end of test turn nozzle up, remove from stack, run aspirator at maximum flow, tap nozzle and pipe; run wire brush through the tube.

6. Calculations:

(a) Dry the sample one half hour at 110° C. and weigh.

(b) Calculate total gas flow through the sampler corrected to 12% $CO_2$ from the chart.

Results of test must be interpreted to decide if the emission from the plant is within the ordinance. If the highest dust loading is not more than 10-15% above the ordinance, the plant can be considered acceptable as a borderline plant. Any possible improvement in operation of a plant should be required to insure that the plant stays within the ordinance. Plants with emissions of more than 15% over the ordinance should be requested to make corrections which will reduce the fly ash emission below the requirements of the ordinance.

References:

[1] Power Test Codes, ASME, PTC 21-1941 Test Code for Dust-Separating Apparatus.

[2] Some Notes on Dust Sampling Equipment and Techniques by W. C. Holton and E. J. Scholtz, Battelle Memorial Institute, Columbus, Ohio.

# Locating The Offender

*by* CHARLES W. GRUBER, Chief Smoke Inspector, Cincinnati, Ohio

"Locating the Offender" responsible for a dust nuisance condition can be a vexing problem or an easy one, depending upon a number of circumstances associated with the condition. Thus, if the offending stack is isolated, the dust is in big chunks, its color is dark, a snow has freshly fallen and an inspector can get to the area before the snow melts, any air pollution control inspector can walk right to the offending stack and have little trouble in convincing plant management of their responsibility in the matter. Black fly ash on white snow is impressive. On the other hand, if a suspected source of a justifiable complaint is buried deep in a maze of plants, several of which are potential sources, then the job calls for all the knowledge and skill the air pollution enforcement official can muster.

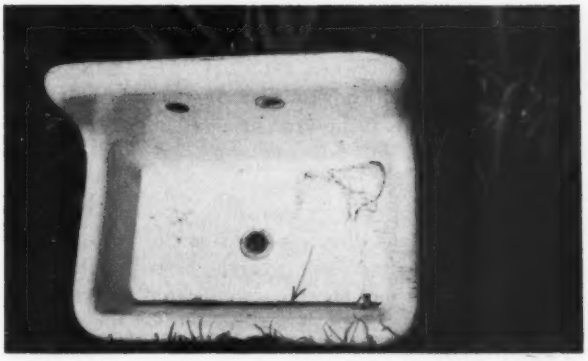
Our approach to the problem of determining the source of any air pollution is to utilize the more simplified techniques as our budget does not provide for refined laboratory studies and broad scale area investigations. Therefore, this paper on "Locating the Offender" will describe the more simplified practical approaches rather than attempt to tell of the more highly technical approaches.

*Rock wool emission shows clearly against dark garage roof. Overnight collection.*

Two objectives must be considered when one sets out to "Locate the Offender." One objective is to develop and preserve sufficient evidence to convince a *cooperative* management that, beyond a reasonable doubt, their plant is the source of the nuisance complained of. The other is to prepare and preserve evidence for prosecution in court for violation of a particular ordinance or statute. The first objective is the one which air pollution control officials are ordinarily called upon to pursue. The second objective is very important, but the means of developing evidence of violation is so dependent upon the provisions of the ordinance or statute that it could not be covered in the short time allotted for this presentation. Therefore, this discussion will be presented in the light of the former objective.

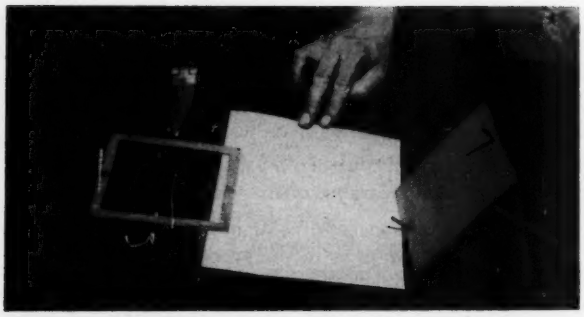
Considering the fact that the purpose of an investigation is to develop evidence which may or may not be legal proof, but which would be sufficient to convince management to do something about a particular situation, the following items are important:

1. The air pollution control official must have a thorough knowledge of the dust emitting potentialities of various fuel burning equipment and industrial processes. Examples of such potential sources are:
   (a) A spreader stoker or pulverized fuel-firing equipment without *adequate* dust collectors or defective collectors.
   (b) Underfeed stoker firing with exceptionally high burning rates. When the burning rate exceeds 35 pounds per square foot, there is a good chance that the dust loading out the stack will exceed the limits of the Cincinnati ordinance and that of most communities. Stokers without proper draft control.
   (c) Chimneys without provisions for settling chambers or chimneys which are cleaned by opening the cleanout door.
   (d) The inherent problems of flue blowing.
   (e) The stoker-fired coal locomotive.
   (f) The thousands of industrial processes which require melting, grinding, drying, blending, which are too numerous to list here.
   To illustrate the industries involved, it is only necessary to call attention to the list of Industry Committees under the Technical Coordinating Committee of this Association. A study of these industries will reveal the problems connected with their operations.
2. The air pollution control official should be familiar with the physical appearance of the various dust emissions.
   (a) The size, shape and color of the dust often leads to identification as to the process or source.
   (b) Samples for comparative purposes are very helpful. Our office has gathered more than 100 such samples, all properly identified and cataloged as to suspected or known sources and thus are available in the future. The gathering, storing and indexing of samples is most important.



*Enameled iron sink serves as improvised dust catcher trapping 24-hour dust fall.*

   (c) The use of a magnifying glass or a microscope is helpful in identifying the dust according to its physical appearance.
   In the use of the microscope, proper illumination and selection of the best suited enlargement is a factor. Too bright illumination on the sample often obliterates much of the detail. The use of a colored background, particularly yellow, shows up the true color of the sample better than the common glass slide or white paper background.
3. The pattern of the dustfall in the neighborhood can often reveal the path to the plant without the use of instruments.
   (a) Look for deposits on porches, railings, window sills and other flat surfaces. Don't be fooled into thinking that the dirt comes from the side of the house on which the dirt appears. In many cases, the reverse is true.
   (b) Look for dust deposits on cars, particularly the pastel shades of the newer models and in containers lying around.
   (c) Flowers, leaves and bushes are excellent samplers. Petunias and geraniums have a particular affinity for holding dust deposits.



*Frame and holder for "sticky paper" fly ash deposits.*

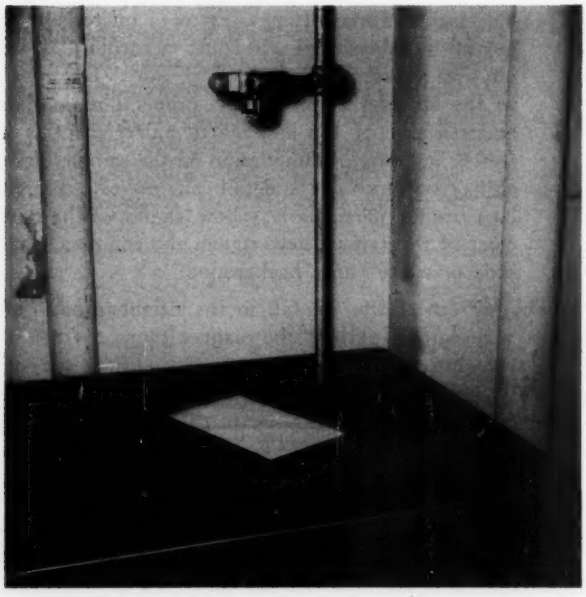
(d) Deposits on freshly fallen snow are very revealing.

(e) Look for dust deposit on your own car or hat after you have stood under a suspected stack for 15 to 20 minutes.

4. Spot samples with sticky paper or greased aluminum foils can be used when necessary. This technique is well known to officials today and works out very well. A flat surface may be used or a square sided vertical block covered with adhesive is a good directional indicator.

   With the use of sticky paper, it is necessary to obtain wind velocity and direction which is always a problem. The shorter the sampling time, the better, as the interpretation will not become complicated by changing wind directions. There is a definite need for an inexpensive portable wind direction and velocity recorder to be used in connection with such tests.

*Camera, stand, and frame for taking photographs of dust deposit on snow.*



*Cylinders of "sticky paper" mounted on battery box stands to indicate directional source of dust.*

5. Laboratory analysis of dust samples in certain instances is necessary in identifying the nature of dusts and to provide a clue as to the source. This approach to "Locating the Offender" is more commonly used in cases where litigation is contemplated as it is expensive and time-consuming and therefore, is not readily available to the average air pollution control official for day to day work in handling the run of the mill complaints.

In summary, it is felt that the most important procedures in identifying an offending stack are the knowledge of potential sources of excessive dust emission and practice in looking at the physical appearance of the most common dust nuisances. Preservation of evidence, particularly in collecting, preserving and identifying samples will be a great help. In the more complex situations, it will be necessary to resort to simplified tests such as short time sticky paper samples and the more elaborate laboratory procedures for determining the chemical nature of the dust deposit. There is no substitute for practice in the field which opens the avenues to the source of dust pollution.

# The Role of The Area Survey in The Control of Dust

RICHARD B. ENGDAHL, Supervisor*

The area air-pollution survey has for its purpose the determination of the main influences affecting air contamination in an area. The data which it produces permit analysis to be concentrated on the important factors involved and on their interrelationships. Fundamentally, it is based on recognition that air pollution is a community problem which, in the long run, is better controlled and treated as a continuous whole and not just as a series of separate short-time emergencies. At all times, it must be recognized that localized problems within the area will arise on which the area data are likely to be insufficiently detailed. But such situations should benefit greatly from a localized concentration of the already established area-measurement techniques.

In attacking the dust phases of air pollution, the area survey is the procedure which adds perspective to the over-all situation. The area survey is quite old in one respect, in that dust-fall measurements over wide areas have been made for many years in England and also in this country in a number of our major cities. The first measurements of dirt fall in the United States were made in Pittsburgh in 1912 by Hamor (1). The availability of more feasible and other specific instrumentation can now be applied to supplement the simple dirt-fall jar to accumulate information of value on dust problems.

One of the deterrent factors in the more widespread use of even the simple dirt-fall jar as a basic measurement in such a survey has been the great dearth of truly comparable data with which any new data can be compared with assurance. It is readily recognized by most that many factors, in addition to the characteristics of the measuring device itself, enter into the over-all influence on any particular set of measurements. It is also obvious that any new set of measurements being made require considerable time before assured data can be accumulated, particularly when the technician, however skilled in other fields, may be making his first attempt at such a measurement. Perhaps the greatest cause for doubt in any method applied to an area comes from the natural tendency to attempt to compare different cities on the basis of average values from such measurements. Usually such attempts are misleading. Aside from the precise configuration of type of device used to make the individual measurements, the local variations of types of dust emitted, proportion of industry to other forms of activity of inhabited areas, predominant types of fuels, topography, meteorology, and population density all combine to make any such average highly suspect so far as comparisons are concerned. For some of these factors, it would be necessary to weight the data in order to produce an average value useful for comparative purposes.

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The area survey, by obtaining data which reflect these variations in an area, helps to place each of these factors in its proper perspective.

### *Type of Dust*

Most regions of concentrated population are characterized by the preponderant emission of dusts larger than 10 microns which settle mostly within the area and which can be controlled readily at the source. If not controlled at the source, they are usually of the type which can be disposed of fairly readily by the neighbor on whom they are deposited. All areas, however, some more than others, must contend with the emission of extremely fine dusts which practically never settle because of their extremely small size. Unfortunately, these fine dusts have the common characteristic that they are extremely difficult to catch in any abatement device or even in some cases to deliver, as dust-laden gas, to any abatement device. Another unfortunate characteristic of this size of material is that it scatters light readily and is thus visible out of all proportion to the amount of dust present. In addition, the composition of such dusts can vary widely from area to area. However, identification of such materials by analyzing the composition of collected dust is not necessarily a simple task because of the usually greater tonnage of local larger dust present in the atmosphere, which tends to mask the specific composition.

### *Characteristic Activities in Built-Up Areas*

The variation in type and concentration of industry from city to city is, of course, tremendous and can account for a similarly tremendous variation in its effect on dust problems. Similarly, the amount, type, and concentration of housing can have an influence on dust emitted.

### *Topography*

To include topography in such a problem is to recognize that nature has always used, and man has been steadily increasing his use of, the atmosphere as a natural sewer into which unwanted gases and other air-borne materials can be dumped. The flow of this natural sewer is essential to its practical use, and topography affects atmospheric flow. A deep valley parallel to the prevailing winds will be swept clean much more regularly than a similar valley transverse to the prevailing winds. As a consequence, the dirt-fall pattern of the one may be quite different from the other.

In addition, the type of soil and the extent of natural drainage of moisture affects the amount of natural pollution which is apt to be swept up by air motion over the earth's surface.

### *Climatology*

Closely related to the factor of topography is the nature of the atmospheric movement in the area, the amount of

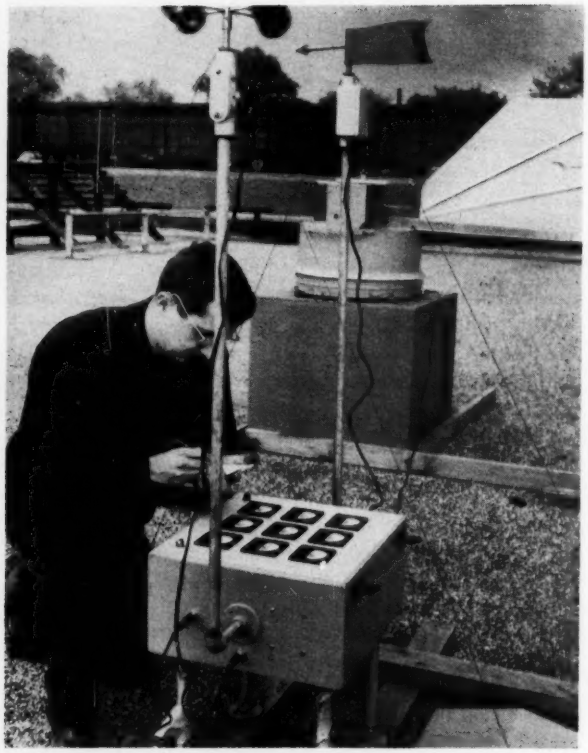

*Fig. 1.—Modified dust fall collector with wind-hour meter.*

rainfall, and the lapse rate. Because of the extreme variability of rainfall from season to season, this factor will introduce another variation in the amount of dust naturally entrained by wind.

### *Traffic Density*

Our high dependence on vehicular motion in centers of dense population probably has a decided effect upon the amount of dust re-entrained in the atmosphere. Extent of street cleaning and type of road surface, of course, can also have an effect on this. A unique but fading example of this situation is the farm house along the dusty country road. Where traffic density is great, the amount of fallen dust re-entrained reaches the point where dust fall in the vicinity is intolerable and an upgrading of surface by oiling or paving is necessary. Because of the tremendous improvement in reduction of re-entrainment through hard surfacing of streets and roads, we are apt to assume that this source of air pollution has been completely eliminated. This may be far from true where street cleaning is poor.

### *Measurement of Atmospheric Dusts*

The interaction of the foregoing factors makes each local situation a different one, and causes each point in any local area to have its own peculiar characteristics. The role of the area survey is to put these characteristics in their proper perspective in relation to the important sources in the area and in relation to the over-all pollution level. A number of useful instruments are available to help achieve this.

### *Stationary Dirt-Fall Jar*

The simple dirt-fall jar is fairly well established as the basic tool in any area survey involving coarse dust. Opinions and practices vary in many minor details of configuration, location, and handling of the jar. Frequently, its value is questioned because data from different areas have seemed to be inconsistent and contradictory. However, as Hemeon (2) has pointed out, misuse of its results should not be allowed to impair its value. It is to be hoped that current work by the Industrial Hygiene Foundation of America will produce data leading us to some reasonable standardization on this useful tool. Meanwhile, until some standard based on thorough comparative measurements can be agreed upon, it seems desirable to adhere to the simplest form of jar possible.

### *Directional Dirt-Fall Collector*

A useful elaboration of the simple stationary jar is the directional dirt-fall collector which was introduced by Munger in 1950. The original concept and mode of operation has been described in detail in a number of papers (3, 4, 5, 6) and will not be discussed here. Briefly, it can be described as a series of jars representing the eight points of the compass and a calm jar, all so arranged that only one jar is open at any one time, and that one corresponding to the direction of wind at the moment. Suitable controls are provided to shift the opening of the device to the calm jar when the wind drops below an arbitrary minimum of 3 miles per hr.

A limitation of the instrument as originally operated was that there was no indication of the rate of dust fall for any of the particular wind directions. Thus, with a certain wind direction being infrequent in a given locality, if the wind blew from this direction during a short period of exceedingly high dirt-fall rate resulting from the nearness of a heavy source of dust emission, this occurrence would not be revealed.

The obvious improvement has now been made to most of the collectors of this type now operating in the field, consisting of a simple wind-hour meter which records the number of hours in a month that the wind blows from each of the eight directions, and the calm periods. Thus, it is possible to calculate the average dirt-fall rate for each wind direction. A plot on circular coordinates of these dirt-fall rates gives a graphic picture of the variation in dirt fall at the point of the instrument depending on wind direction.

Figure 1 shows the modified directional dirt-fall collector with wind-hour meter.

The data so far obtained with directional collectors are not available for publication and hence can not be used to demonstrate the performance of the instrument in detail. However, two instruments are now in operation obtaining data which will be published. Because of the nature of dirt-fall measurements, it will be at least a year

before enough data are obtained to show reliably the type of information which the instrument produces.

Figure 2 is an example of the polar diagram of directional dirt fall which can be obtained with the device.

### *Suspended Dust*

An important measure of atmospheric pollution which cannot be provided by the stationary dust-fall jar or directional collector is the measurement of suspended dust in the atmosphere, which consists of particles so small that the normal turbulence of even the usual low-velocity winds is sufficient to keep them in suspension almost in-

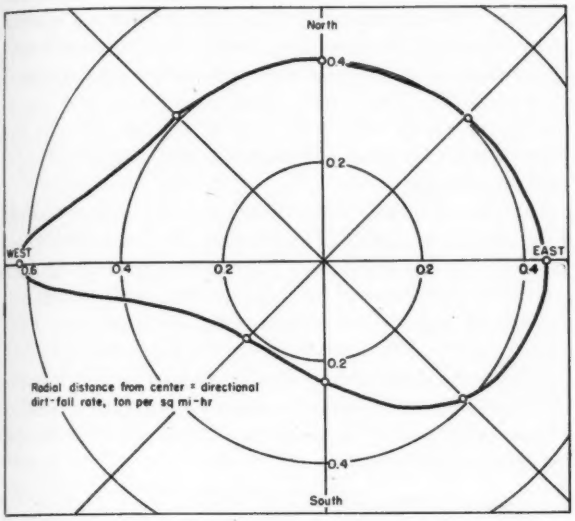


FIGURE 2. TYPICAL POLAR DIAGRAM OF THE INFORMATION PROVIDED BY THE COMBINED DIRECTIONAL DIRT-FALL COLLECTOR AND WIND-HOUR METER

definitely. This is the material about which little is known, or can be known, because of the comparatively small quantity present and the consequent difficulty of determining its properties and characteristics when, in addition, it is dispersed in such small size. Under certain conditions, it is known to flocculate. Under other conditions, if in a critical size range, it is known to reduce visibility markedly. Also it is frequently attracted, by the Aitken effect, to surfaces colder than the surrounding atmosphere. Thus on a clear, warm evening when radiation to outer space cools some objects below the temperature of the surrounding atmosphere, conditions are set up for rapid deposition of the suspended dust well before the surface temperatures reach the point at which condensation occurs and wets the surface. Similarly, when such material is carried by infiltrating air into the interior of living spaces, it is attracted to the cold surface of the outer walls of the structure and gives the noticeable dust patterns characteristic of cold surfaces.

### *Electrostatic Sampler*

One means for collecting this suspended material from the atmosphere is the electrostatic precipitator first developed for sampling in connection with industrial hygiene problems. While it can be set up on a nearly continuous sampling basis, it requires the almost continuous attention of an operator and hence cannot often be used in multiples at many points over an area. Instead, it must be used in an area survey as a part of a program of spot sampling to establish the level and variation of this type of contaminant.

By means of the emission spectrophotometer the important elements in such samples can be determined approximately, and in the immediate vicinity of a concentrated source of a certain type of such dust it seems possible to establish the level of concentration of this particular component. However, consider the case where three-micron particles are predominant in the area from general air-pollution sources. And suppose a single source is putting out predominantly 0.3-micron material which, incidentally, is near the point of maximum visibility. In any atmospheric sample there would have to be 1000 times as many particles of the 0.3-micron dust as of the typical dust of the area in order even to equal the weight of the typical material present. Thus, only if the sampling is done extremely close to the source, it is likely that chemical analysis alone can be used in identifying the source of a particular material.

### *Thermal Precipitator*

The principle of the net driving effect of a temperature gradient across a layer of gas in moving suspended particles toward the cooler boundary surface has been embodied in the thermal precipitator, which has been considerably refined by Stokinger and Laskin (7). This precipitator operates with much smaller forces than the electrostatic precipitator and so is likely to separate out only the very smallest particles in the atmosphere; the refinement permits them to be distributed over a slowly moving surface during the sampling period. Thus there is a possibility that, if a particular kind of dust being emitted is characterized by a size consist almost unique and distinct from that characteristic of the area, microscopic examinations or chemical analyses can be employed with this instrument to establish a level of contribution and the source of a particular contaminant. The extremely small amount of sample which is collected by this type of sampler makes it even more tedious to use than the electrostatic precipitator and considerably limits its scope.

### *High-Volume Sampler*

The high-volume sampler has been described and used widely. It consists of a motor-driven blower which pulls the atmospheric sample through a pleated paper or cloth or other type of filter. It is weatherproofed so it can be set out at a suitable location and operated for many hours at a time. The filter can be cleaned of its liquid and solid aerosol content and the material analyzed chemically and, to some extent, microscopically. Although it could conceivably be set up in a directional pattern, this would be rather complicated and the problem of processing the

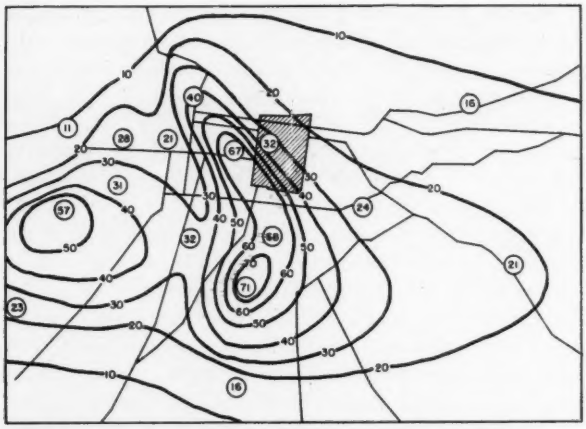

FIGURE 3. TYPICAL MAP OF COARSE DUST FALL IN AN AREA SHOWING LINES OF CONSTANT FALL

multiple filter pads would be great. Consequently, it has been used mostly to give an idea of the general level of suspended contaminant in an area. As with the simple coarse-dirt-fall collector, it gives no indication of the rate of deposit of material at any time during the period of operation. Thus, a particularly noticeable concentration of material might go unnoticed if it occurred either before or after a period of sampling when the concentration of that material was comparatively low.

*Other Methods*

For coarse dust, the use of the Petri dish (8) has been described in connection with the Leicester studies in England and recently Hemeon (9) has described the use of coated glass slides dispersed over an area for almost instantaneous measurement of dirt-fall rate. The use of sticky paper has also shown promise.

For suspended dust the continuous sampling of the atmosphere through a moving strip of filter paper has been applied by a number of investigators, and as means are improved to attach useful numerical values to the filter deposits this method will become particularly helpful.

INTERPRETATION OF AREA RESULTS

In general, the results of the dust phase of an area air-pollution survey will show the local and seasonal variations of coarse-dust distribution in the area and the composition of the suspended and coarse dust.

In the case of coarse-dust fall, plotting the monthly figures for dust fall for each station on a map of the area and using this to guide the drawing of lines of constant dirt fall helps considerably to establish the areas which have maximum and minimum fall. Figure 3 shows a plot typical of this method. Depending on the number of sources in the area and the frequency distribution of the stations, it may be possible to pin point specific sources by this means. Such plots for combustible matter and ash have been published for all of England (10). It should not be surprising that the centers of highest fall are around London and the Manchester area. Similar, but much more concentrated and specific, maps are being accumulated by the Smoke Regulation Department of Columbus, Ohio. These are quite consistent from month to month and promise to give an interesting picture of coarse-dust fall when a sufficient number of maps has been accumulated.

*Chemical Analysis*

Some additional information can be obtained from the collected material if it is analyzed. Meetham (8) states that in the English studies, in heavy industrial areas the proportion of incombustible to insoluble matter is much greater than in the country, and in terms of actual deposit may be hundreds of times as heavy. On the other hand, in those same industrial areas, the deposit of soluble material is seldom more than double that in the country. He explains that the soluble material leaving most industrial stacks is either in very small particles or as a vapor, neither of which would settle in a dirt-fall jar. On the other hand, the insoluble materials are usually all solid and much larger in size.

On the other hand, the chemical composition of dust from station to station probably does not vary significantly except in extreme cases, although the paucity of data on this point prevents adequate proof of this statement. Studies of high-volume dust samples in Louisville, Kentucky, by Carlson and others (11) showed only small variations in composition of sampled dust. Table I shows the results for 10 sampling stations over approximately a 15-square-mile area including both heavy industrial and exclusively residential areas.

TABLE 1. *Average Dust Composition by Stations*

| Station | Per Cent $Fe_2O_3$ | Per Cent $SiO_2$ | Per Cent $Al_2O_3$ | Per Cent CaO | Per Cent MgO |
|---|---|---|---|---|---|
| 1 | 11.2 | 27.8 | 13.8 | 9.8 | 19.4 |
| 2 | 12.0 | 32.2 | 12.1 | 9.3 | 8.1 |
| 3 | 9.8 | 28.4 | 13.9 | 11.7 | 17.2 |
| 4 | 10.3 | 25.8 | 16.8 | 11.4 | 20.1 |
| 5 | 8.4 | 26.0 | 13.3 | 11.2 | 20.7 |
| 6 | 9.3 | 19.9 | 19.3 | 10.9 | 8.8 |
| 7 | 11.3 | 25.6 | 19.2 | 8.1 | 9.0 |
| 8 | 18.3 | 30.4 | 16.1 | 8.0 | 14.2 |
| 9 | 11.5 | 26.7 | 15.6 | 10.7 | 13.7 |
| 10 | 9.7 | 24.6 | 18.1 | 14.0 | |
| Avg. Over-All | 11.2 | 26.7 | 15.8 | 10.5 | 14.5 |
| West End | 11.1 | 26.6 | 16.1 | 10.6 | 14.0 |
| Central Louisville | 11.5 | 26.7 | 15.6 | 10.7 | 13.7 |
| Avg. Stack Values | 18.7 | 25.9 | 12.1 | 12.4 | 13.7 |

Similarly, Hemeon (9) showed little variation in suspended-dust composition in the recent studies in New Haven, Connecticut.

*Unusual Problem of Identification*

A recent unusual example of the difficulty of identifying dust sources is the investigation by Thomsen (12) of meteoritic dust by means of its magnetic properties. Samples were collected from melted snow, by magnetic means from roofs, and by simple dirt-fall cans in the vicinity of Iowa City, Iowa.

Spectrographic analysis of the dark, shiny, magnetic spheres obtained showed no nickel, principally silica and ferrous oxide. They ranged from 10 to 50 microns in size. The weight rate of fall of the magnetic spheres was calculated to be about 2 pounds per square mile per month. Others have estimated meteoritic-dust fall to range from 0.003 to 3 pounds per square mile per month.

However, Handy and Davidson [13] have pointed out that some typical pulverized-coal ashes range from 3 to 17 per cent magnetic, that these too are largely silica and ferrous oxide, and that in North America the rate of loss of magnetic flyash is about 80,000 tons per year, which is about equal to the dust-fall rate measured by Thomsen. Thus there appear equal chances that the dark, shiny magnetic spheres are man made or extra-terrestrial dust.

### *Seasonal Variations*

The data given by the simple dust-fall jar can usually be expected to indicate consistent seasonal variations if the measurement program is carried out over a number of years. This is usually brought about by variation in fuel consumption, variations in moisture, and in wind. For this reason, the comparison of any one month with any other month in any other locality is open to considerable question. Even the comparison of any one year with another area is questionable and, as has been indicated before, because no two areas are alike in all of the many factors influencing dirt fall, they will not permit detailed comparisons in any fashion. The best comparison is within the area itself over a period of years.

### *Summary*

An attempt has been made to point out that on the dust phase of air pollution the many extraneous variables interacting at any point limit greatly the value of data taken at one point only. Simultaneous measurements at many points over an area are required to give a picture which will bring out the influence of the main variables of interest. The principal practical tool available for such an area survey is the simple dirt-fall station. Some modifications show promise.

Equivalent means for getting the picture on suspended dust are not available. And the rapid weight-wise dilution of ultrafine, highly visible clouds of fine dust by the larger dust particles normally raised in an inhabited area, make chemical identification of the visible components of the cloud extremely difficult. An unusual example of the difficulty of identifying the origin of fine deposited dust is the problem of distinguishing between flyash and meteoritic dust.

The need is great for research to improve existing means for all kinds of dust measurement and to develop entirely new and more rapid means for such measurements.

### *Acknowledgments*

The assistance of the members of the air-pollution research group at Battelle is gratefully acknowledged, together with that of the many engineers, research workers, and officials in this field who are striving to make the art more of a science. Particular thanks are due L. P. Akers, chief chemist, Louisville Gas and Electric Company, who brought the subject of meteoritic dust to my attention.

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# Troubles and Remedies of Air Pollution Control on the Railroads

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The unplanned mushroom growth of America's cities created many difficulties, among which was the appalling increase of smoke and dirt. The railroads contributed a considerable part of this smoke, and it is fair to state that most smoke ordinances were originally enacted to lessen smoke from railroad locomotives. This is understandable as the busy switch engines moved all over the cities, in and out of each factory siding, and bringing a smoking stack close to most homes. When the people looked for the source of their dirt, the locomotives were the visible answer.

During the early years of this century the use of the small, hand fired, coal burning locomotive was standard equipment on the railroads, and required the utmost from a crew to move their trains. The highest praise for a locomotive fireman was to say he could keep an engine hot under all conditions.

Constant increases of tonnage spurred the building of larger, more powerful locomotives, and this complicated the railroad problem still further. The locomotives had to have better boiler and machinery metals to withstand the increased pressures and greater strains. The use of welding somewhat replaced rivets and lapped seams. The boiler water was treated to prevent scale and improve steaming qualities; preheaters utilized exhaust steam; superheaters economized on fuel and water and reduced back pressure. Thru the years every phase of railroading was closely scrutinized, new methods were adopted, and the art of railroading became more efficient. The mechanical stoker relieved the fireman from the shovel method of firing, and he became more smoke conscious, as a stack of black smoke was a sure sign of poor firing.

New freight terminals were built, miles out from the cities, and the new engine houses often provided direct steaming for locomotives. Better blowers were possible with the higher steam pressures. Experiments and tests have developed good smoke consumers, and fire-up torches. All these things provided tools needed to control smoke and dirt from locomotives. However, there was a lamentable tardiness on the part of the railroads in utilizing to the utmost the improved equipment that would bring about a reduction in smoke and dirt.

The cities continued their pressure on the railroads for better control, until the management took a new, long look at this problem, and decided as a definite policy that smoke and dirt in all its various forms could be brought below tolerable limits. That was the beginning of real smoke and dirt control on the railroads. With the top brass breathing down their necks, each department supervisor was obliged to study the problem as it related to his own men, and teach and discipline those who failed to conform to rigid requirements. Books of Rules of many railroads were revised to penalize excessive smoke, anywhere on the railroad. Studies were made of each step in standby service, and the Road Foreman of Engines worked ceaselessly to demonstrate that it was practical to fire engines at capacity with clear stacks. Excuses were rejected when men were reported. Smoke became unpopular, and was less frequently observed. Repeated offenses were disciplined, but it speaks well for the soundness of the program that very few men have been discharged. Real improvement was only attained when better locomotives, determined management, and cooperating employees joined forces to improve their record on their own railroad. There was just no other way it could have been done.

Most air pollution from railroads has always been caused by the movement and coupling of cars in train yards, by the dust raised from moving trains, and most of all from wind blowing across the properties. Careful analysis of complaints over a period of years shows that when high winds blow from large open areas toward residential sections, the people affected are prone to protest, although no reportable smoke or dirt is being made. Conversely, there have been numerous smoke violations observed where there have been no complaints from the nearby residents. Investigation, made as soon as the people call up, has sometimes shown the source of pollution to be from other than a railroad origin.

The railroads strive to hold and improve their present proven record of cooperation with every city, as all taxpaying citizens should gladly do, and to be a servant to all the people of these United States.

# Sampling and Measurement of Radioactive Atmospheric Pollution

*by* W. B. HARRIS, Chief, Industrial Hygiene Branch
and
H. D. LEVINE, Chief, Instruments Branch
*Health and Safety Division, New York Operations Office,*
*U. S. Atomic Energy Commission*

The problem of sampling for radioactive atmospheric pollution, in general, is divided into two distinct fields. The first of these involves the measurement of radioactive materials which have been discharged by plants or laboratories processing radioactive materials. The second is concerned primarily with materials which have been thrown into the air by a nuclear detonation.

*Stack Effluents*

We have used two types of equipment for monitoring ground level contamination arising from radioactive effluents from a stack. The first of these is shown in Figure 1. A complete description of this unit has been published (1) but I will attempt briefly to describe some of its features.

The operating principle of this dust monitor is to obtain one-hour samples of atmospheric dust automatically on a

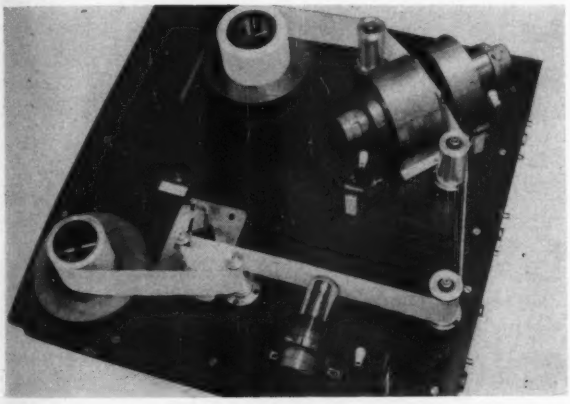


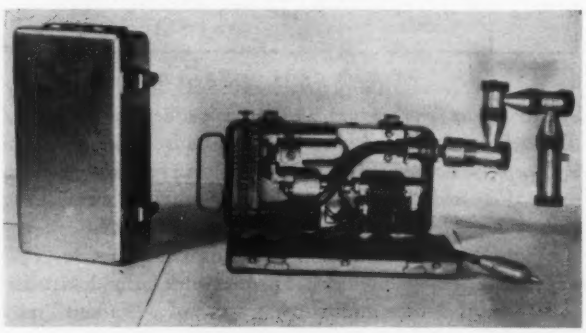
*Fig. 1.—Atomic dust monitor.*

suitable filter, and simultaneously to analyze and record the alpha and beta activity levels of the airborne dust. For this purpose, there are three units for counting radioactivity mounted on the equipment facing the tape. Unit #1, which is located in the upper right-hand corner of the figure, measures alpha particle activity immediately on completion of the sampling period. This provides a measure of all alpha activity including the concentration of decay products of radon, which are normal constituents of our atmosphere. Directly facing this, on the opposite side of the tape, is a beta particle sensitive unit which analyses the dust sample for beta activity. The third tube, located in the lower center of the figure, re-counts the alpha activity in the sample after a delay of ten hours. During this time, the short-lived alpha emitting materials have decayed to a negligible fraction of their original concentration and the resultant analysis indicates only relatively long-lived alpha emitters, such as uranium, thorium, radium, or polonium. By properly weighting the three results, it is possible to make a determination of the radioactive atmospheric constituents. It should be pointed out that this equipment which operates at a rate of 10 cubic feet of air per minute through a 1½" diameter sample would also be very effective in providing a measure of total atmospheric contamination. If a fourth photoelectric device were added, it could function either as a transmission or a reflection densitometer and provide a measure of total dust as described by Hemeon (2).

The apparatus described above is used as a control device in order that a continuous record may be obtained and kept. When it is desirable to pinpoint sources of contamination or to determine the degree of contamination discharged by a process or stack, the measurement problem is somewhat different. As pointed out by several authors (3, 4, 5), the most effective way to establish degree of pollution from a contaminating source is to set up mobile sampling stations in a downwind direction from the emitting stack. As a practical matter of obtaining results, this is frequently very difficult in that within a space of several thousands of feet power sources to drive equipment requiring 110 volts at the desired locations are not usually accessible. Anyone who has attempted this, has, I am sure, had the same difficulties which we have found and as a result ended up with gasoline generators as a source of power, with all their attendant problems.

Figure 2 (6) shows a device which may be operated either from a fixed storage battery location or may be mounted in a motor vehicle. The device has been pro-

*Fig. 2.—Six-volt battery operated air sample.*



vided with a cigarette lighter type of plug so that without any wiring it may be "plugged in" to an automobile. This device will draw approximately 0.5 cubic feet of air per minute through a filter with a resistance of between 1″ and 2″ of mercury. The pump mechanism has been designed for continuous operation and has been provided with oilless bearings and graphite vanes.

The electrical drain of the air sampler in field operation is approximately 5 amperes, which will permit 16 consecutive hours of operation from the usual automobile battery without the necessity for recharging. If longer periods of sampling are desired at the same flow rate, it would be necessary to provide several batteries or some means for field charging.

Samples which are obtained from this 6 volt dust sampler may then be returned to a laboratory for analysis. In this office, we collect the samples on a 1⅛″ diameter filter paper which readily lends itself to radioassay of active materials.

*Fallout*

The other area requiring determination of radioactive atmospheric contamination mentioned above, will probably be a continuing governmental function. This arises from the requirements of testing various developments in the field of nuclear devices and weapons. Again, the procedure divides itself into two categories of operation, one of which involves permanent fixed locations in order that routine data may be collected to discover the pattern of fallout and any anomalies, and the other involves highly mobile spot checking of the atmosphere within a relatively short distance of the source.

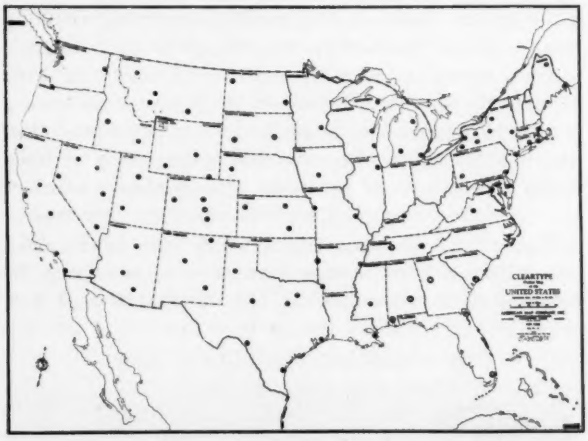


*Fig. 3.—Network of fixed monitoring stations.*

Because of the nature and magnitude of this type of dispersion, contamination which results from a detonation is apt to be extremely widespread although of a very low order. Figure 3 shows the network of stations which have been set up by the New York Operations Office of the Atomic Energy Commission to monitor radioactive "fallout" on a permanent basis. This network provides statistically equivalent annuli so that areas of a "fallout" may be defined. The concentration of stations increases toward the northeast because of the greater population density in this area. The network operates all year round on a skeleton basis with operations brought up to full scale from several weeks before until four weeks after the test period. Each of these stations, which are operated by Weather Bureau personnel, is provided with the equipment shown in Figures 4 and 5.

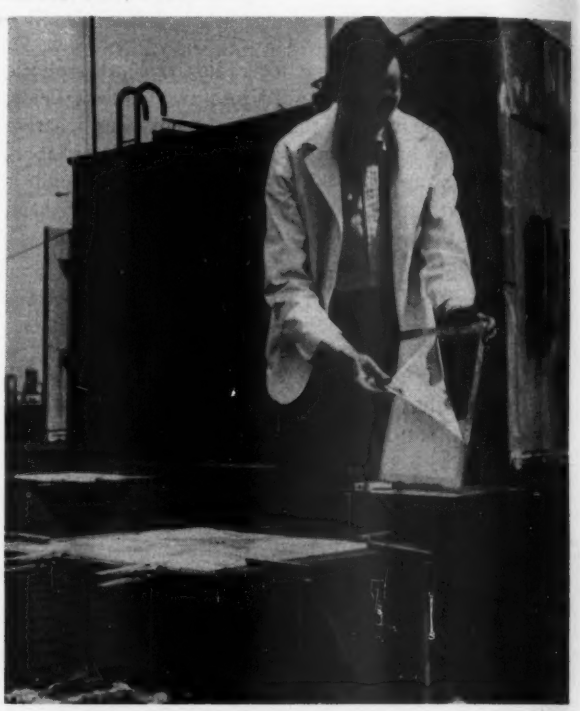


*Fig. 4.—Gummed paper stands.*

Figure 4 shows the equipment which is used for the collection of "fallout." In this case, the steel frame which is being held in the center of the figure has fastened to it, an adhesive coated film, with the adhesive side up, and is clipped, as can be seen, to the top of a metal stand. Three such stands are placed on 6 foot centers in a triangle in order that triplicate samples can be obtained. The samples are collected by exposing the gummed surface of the sample paper to material falling from the sky for 24 hours, at the end of which time they are folded, gum side in, and shipped to the laboratory.

Figure 5 shows equipment which samples the atmosphere on a continuous basis and collects on a filter the airborne particulate material. The equipment shown in this photograph is a high volume sampler as described by the authors (6). Of special interest in this figure is the shelter in which the dust sampler is held. This shelter is a modified fiber carrying case, both ends of which drop down permitting transit of the air. This case serves the purpose of a shelter, a carrying case, and a shipping container. It was comparatively inexpensive and has proved to stand up very well under extremes of weather con-

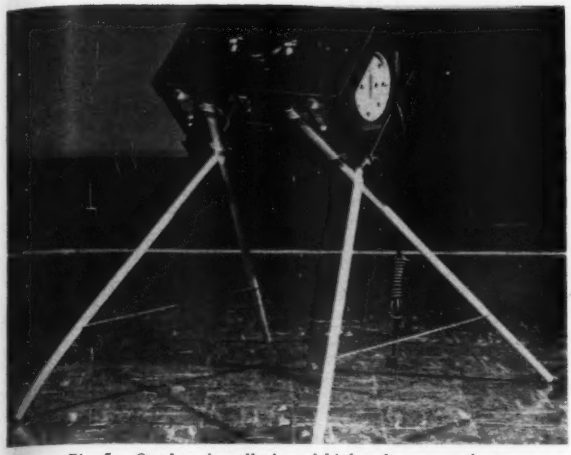


*Fig. 5.—Outdoor installation of high volume sampler.*

ditions in all parts of the country. The case is elevated above the ground by the detachable legs shown in the photograph. The samples taken by this unit are also shipped to a central laboratory for analysis.

In obtaining data from close to the source of contamination, the approach is necessarily somewhat different. Here the fallout is heavier and fairly well defined. Excessive concentrations have never been found, but the samples are taken in such a way that a reasonable evaluation of potential risk may be made. In addition to this type of

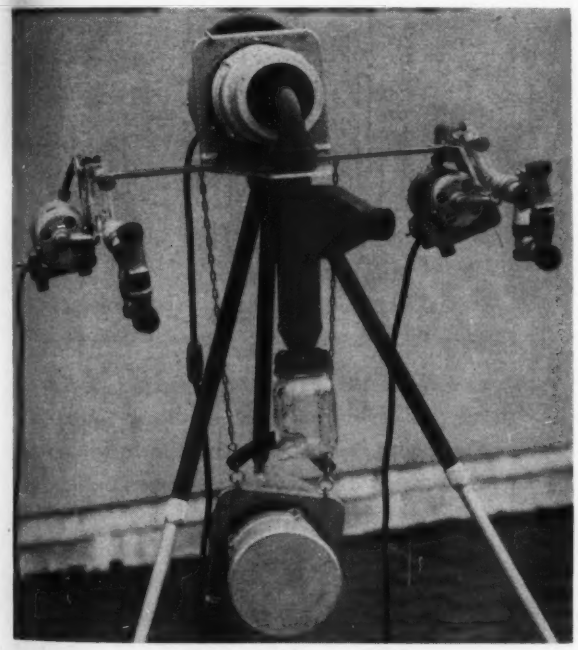


*Fig. 6.—"Christmas tree."*

sampling, another criterion which must be satisfied is that the equipment be light-weight for aircraft transport, be easily dismantled and set up for rapidity of transfer, and be possible of packing in a relatively few packing units.

Figure 6 shows a complete air sampling setup which we

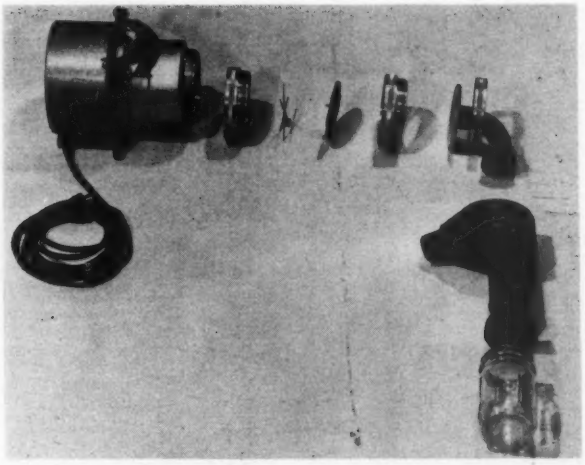


*Fig. 7.—Hi-Vol Aerotec assembly.*

call the "Christmas tree." This contains four air sampling devices obtaining typical high volume samples (1 cubic meter per minute) and typical low volume samples (17.5 liters per minute). The low volume units sample the air through 5-stage cascade impactors thereby providing the spectrum of particle size distribution. One of the high volume samplers is equipped with a high velocity small diameter cyclone which collects and separates out the larger particle sizes.

In Figure 7 is shown a breakdown of this Aerotec sampling unit and shows the filter paper which picks up the material going through the primary separator.

The equipment which is used to analyze these samples has been described (7). The tremendous load of samples which this program involves precludes much manual analytical work. The laboratory, therefore, had to devise equipment as automatic as possible for the analyses.

In Figure 8 is shown the automatic counting device which analyzes the beta activity in the ashed sample. Briefly, when the sample is received at the laboratory, it is incinerated in a high temperature muffle and the ash transferred to a 1″ diameter plastic planchet. This planchet is then sealed between two thin vinyl tapes by induction sealing and rolled on a reel of 100 samples. The samples are counted by means of an end window Geiger tube across the top of which the sample is drawn by an automatic transport. Sample number, counting time, and total disintegration count are printed on the tape. Results are expressed in disintegrations per minute.

In order that the maximum information may be obtained from the filter samples taken by the mobile teams, it is desirable to take the samples as frequently as possible. The optimum unit of sampling time has been found to be about 20 minutes. This period, however, if carried throughout the sampling time, would impose a tremendous burden on the analytical laboratory. It is therefore desirable that samples be taken for a longer term except during the actual period of high level fallout.

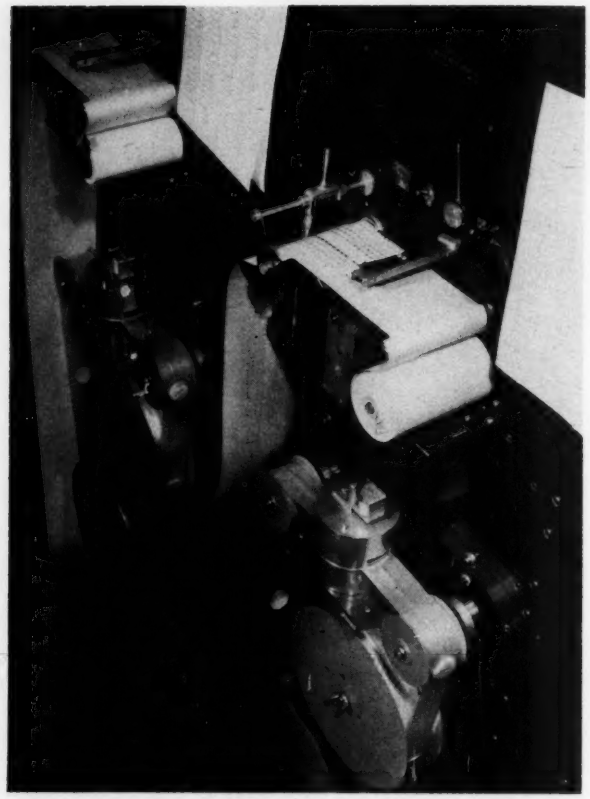


*Fig. 8.—Automatic beta sample analyzer.*

In Figure 9 is shown a modified Geiger Mueller survey meter using an end window Geiger tube. This equipment is carried by the mobile team operators and after the high volume sampling equipment has been put in operation, the operator holds the tube over the sample paper every 20 minutes. As soon as the activity level begins to mount rapidly this is noted on the meter and a routine of 20-minute-sample changes is initiated. In this way a pattern of results similar to those shown in Figure 10 is obtained. It can be seen from this figure that the difference between normal and peak activity is likely to be several orders of magnitude.

In some cases the terrain on which the fallout occurs is not easily accessible. This is true when the fallout occurs on an island or in heavily mountainous terrain. Under these circumstances it has been found desirable to locate areas of contamination from the air. In Figure 11 is shown the "Scintillog" [8]. This equipment is made in two parts. That in the lower left of the figure is a sensitive element which is generally placed in the tail of the surveying aircraft in order to be remote from any possible radioactivity. This consists of a photomultiplier tube, which measures the light from a radiation sensitive NaI(T1) crystal 1½" in diameter by 1" in height. The larger piece of equipment shown in the center includes the power supply, a loud speaker, microphone, and tape recorder. The recorder has two recording heads, one of

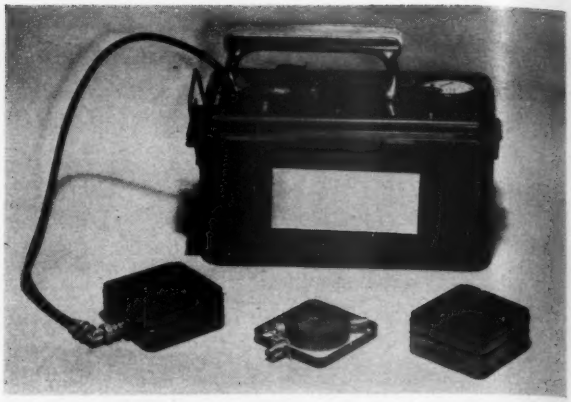
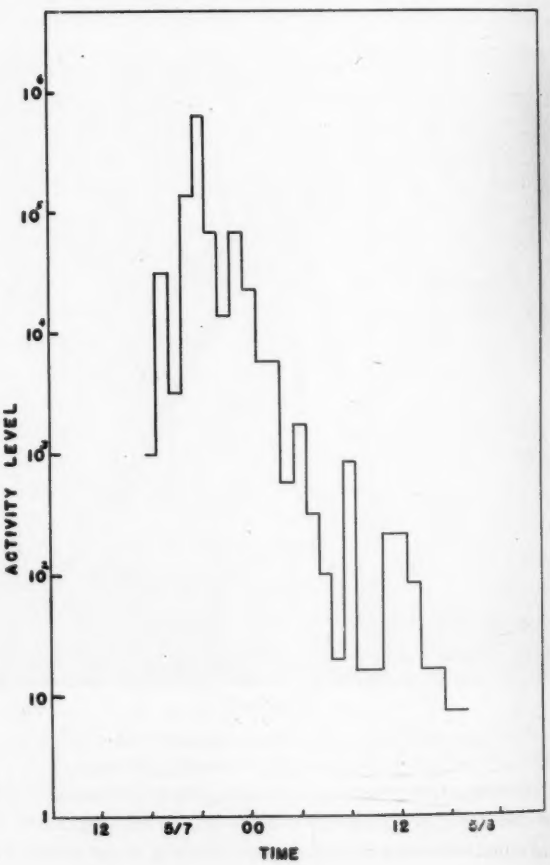


*Fig. 9.—Field screamer for beta activity.*

which transcribes the activity levels which are transmitted from the measuring unit as a d.c. signal. The other transcribes terrain features as described vocally by the operator. In this unit is also placed a meter which registers activity levels for the guidance of the operator. This has been found to be a very effective way of locating the areas of activity with precision. Recording position at the high speed of aircraft travel by any means is apt to make such definition very difficult.

*Fig. 10.— Radioactive dust concentration, Ogden, Utah.*



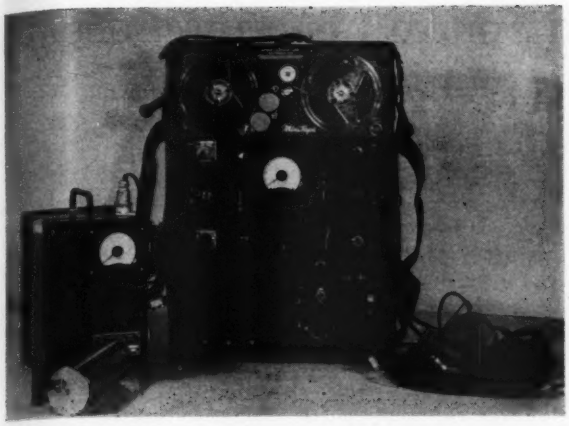


*Fig. 11.—Scintilloger—airborne detector.*

Another device which has been employed in remote or difficultly accessible areas is a trigger device sensitive to gamma radiation. This device is pre-set to trigger automatically at any predetermined activity level and throw on a battery operated air sampling device. Thus, the equipment may be placed on location long before required and it will begin operation only if a radioactive cloud passes overhead. The sampler will then turn itself off as soon as the sampling period is completed.

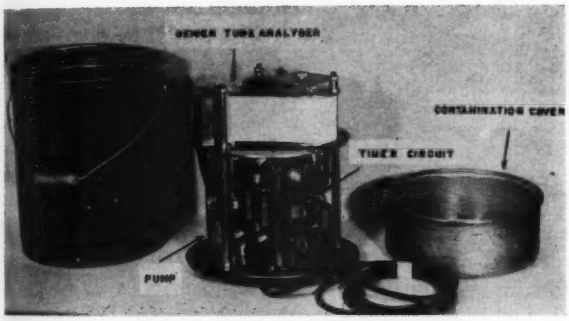



*Fig. 12.—Automatic radioactivity sampler and analyzer.*

In Figure 12 is shown a portable automatic sample taker with strip chart recording analytical equipment. This device, completely contained in a 5 gallon shipping container, has been under test during the Spring 1953 test series. Two models of this unit have been built, one for 6 volt operation, and one for 110 volt operation. It appears from the results, that this equipment can be successfully used to describe atmospheric contamination at the levels of activity which are found within 500 miles of an atomic explosion. A device such as this has a tremendous advantage in that a negligible correction for activity decay is required. The equipment records the analysis of activity at the time of sampling precluding the necessity for an assumed extrapolation.

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# Air Pollution Loophole

*Top editorial in the August 5, 1953 issue of the Philadelphia Evening Bulletin*

It is not only in enforcement of the air pollution ordinance that loopholes can be found. There are some in the ordinance itself.

That was apparent Monday night. A summertime aroma far from that of newmown hay pervaded South and Central Philadelphia. It brought a flood of inquiries and descriptions that it was a mixture of fermented mash and fertilizer.

However, the City Health Department found that the odors were not harmful to health, unpleasant as they were. Consequently, it was powerless. Fumes may make life virtually unbearable, but unless they threaten health nothing can be done about them.

Meantime there are some weak spots in enforcement, too. More than one industrial plant spews out its black smoke daily and nobody seems to care. It's no wonder that on many a morning a pall hangs over the city, plainly visible to suburban commuters who find the sun obscured before they're far into the city.

Air pollution control obviously needs a better ordinance as well as better enforcement if it is to be effective.

# Determination of Haze and Smoke Concentrations By Filter Paper Samplers

*by* W. C. L. Hemeon,
George F. Haines, Jr. and Harold M. Ide*

We have discussed elsewhere (1, 2) the logic in classifying air pollution by particulate matter in accordance with the nature of the soiling effect on surfaces, dust fall nuisances being caused by coarse particles heavy enough to be deposited by gravity on horizontal surfaces and fine particle nuisances whose soiling effect occurs by deposition, in spite of gravity, on walls and ceilings. This classification obviates any need to define the particles found in terms of their size. This discussion is concerned with the fine particles (which usually means fuel smoke particles).

The method of obtaining a visual indication of the atmospheric concentration of "smoke" in which air is aspirated through white filter paper is old. Owens (6) was the first to design and apply an automatic instrument for obtaining a continuous record by a sequence of spots on filter paper. He employed a color chart whereby individual samples were evaluated by visual comparison with the standard chart, each shade being designated by an arbitrary 1, 2, 3 scale.

More recently, and quite independently of each other, three different samples of this nature have been described by Hall (3), Wilson (4) and Hemeon (5), each identical in principle though with different rates of air flow and of filter area.

### *Methods for Sample Evaluation*

The value of this type of sampling would be greatly enhanced if it were possible to evaluate any sample in terms that were fundamentally logical, properly descriptive of the true quantity of such solids present and without regard to the air flow rate or active area of filter paper.

In this paper we offer a method for the evaluation and interpretation of filter paper samples which is simple, independent of the operating characteristics of a particular sampling instrument within certain limits and which can be usefully applied to the assessment of smoke and haze solids from chimneys. This development was stimulated by a reading of the recent contribution by Hall but differs from his treatment in some important essentials.

### *Optical Density*

The optical principle, known as Beers Law, and which is widely applied in laboratory problems in colorimetry and turbidimetry is expressed in the following equation:

$$\log \frac{I_o}{I} = k\,Q$$

where I refers to the intensity of light received from a source after transmission through a fluid suspension of a sample in which some light is absorbed.

$I_o$ is the initial intensity, 100 per cent, i.e., the light passing through a fluid containing none of the "sample," and the quantity.

$\log \frac{I_o}{I}$ is known as the *optical density.*

k=the constant of proportionality

Q=quantity of the sample in the suspension

### *Optical Density versus Smoke Quantity on Filter Paper*

While there is no good reason for supposing that this relationship would certainly apply to particles that had been "condensed" by deposition on the fibers of filter paper, the relationship was explored since, if a simple relationship could be found, it would provide a logical basis for describing quantities of light scattering solids.

For reasons that will appear in later discussion, we deemed it important to avoid use of weight units for describing the quantity of smoke, Q, and succeeded in this by devising the following experimental method to establish the relationship between quantity of solids and intensity of light transmission.

A number of paper filters were mounted separately in suitable holders, each with its own flowmeter. Outdoor air was aspirated simultaneously through all of them at varying air flow rates and for some convenient period of time. In this test arrangement, the "smoke" sample was identical for all filters. The quantity of each was, therefore, proportional to the total quantity of air drawn through them. If the optical density, calculated from the light transmission values, as previously described, were proportional to the relative quantity of "smoke" (i.e. air

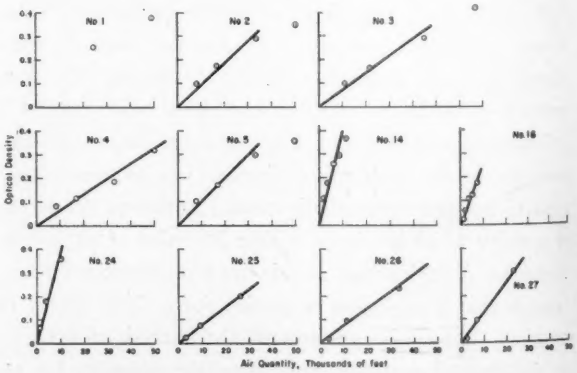



Fig. 1. SEVERAL SEPARATE TESTS SHOWING APPROXIMATE STRAIGHT LINE RELATIONSHIP BETWEEN OPTICAL DENSITY AND SMOKE QUANTITY (Whatman No. 4 Filter Paper)

*Mr. Hemeon is Director of Engineering, Industrial Hygiene Foundation, Pittsburgh, Pa. Mr. Haines is a chemical engineer and Mr. Ide a research associate with Industrial Hygiene Foundation.

volume), then a plot of optical density against air quantity would result in a straight line, and the result could then be said to conform to Beers Law.

*Test Results*

The results of a number of runs on different days, and therefore, different smoke qualities, is given in Figure 1, and show that a straight line approximates the relationship at low optical densities. Divergence from a straight line occurs above certain values of optical density. It appears, however, that if the quantity of air sample were limited to maintain optical density below about .03 (light transmission, not less than about 50%), the divergence from the straight line relationship would not be important, especially in view of the fact that any one value would, in practice, be incorporated into an average value comprised of large numbers of other measurements.

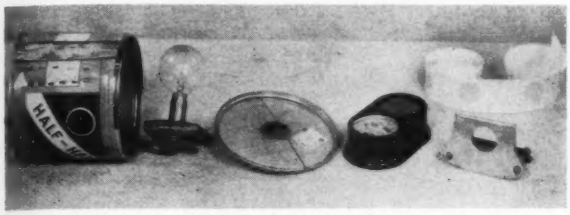


*Fig. 2.—A homemade assembly is entirely adequate for measurement of light transmission. Show here, left to right, is a 100-watt bulb in tin can housing and an ordinary foot-candle meter.*

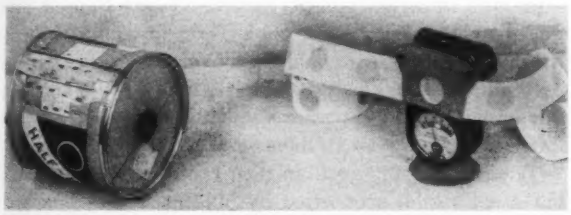


*Fig. 2a.—Assembled view.*

Another test of the validity of this assumption is in the data presented in Table I, which were obtained by a simultaneous sampling arrangement in which the optical density from 6 separate one-hour samples, taken in succession, is compared with similar samples covering the same time period, covering 3 two-hour samples, 2 three-hour samples, and 1 six-hour sample. The extent to which the average values for each differ from each other is an indication of the inherent error due to departure from a straight line. They show that for periods up to 3 hours, the error does not exceed about 15 per cent.

*Fig. 3.—A convenient assembly for determination of optical density by light transmission. Light cell at left, light source, center, and microammeter at right.*

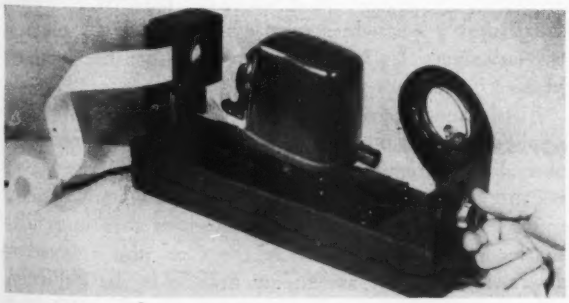


TABLE I

Comparison of Smoke Concentrations Obtained in Simultaneous Sampling with 4 Filters Spanning 6-Hour Periods. (Figures are proportional to optical density divided by air quantity).

| | Average Concentration From— | | | |
|---|---|---|---|---|
| Test No. | Six 1-hour samples | Three 2-hour samples | Two 3-hour samples | One 6-hour sample |
| 1 | 2.0 | 2.1 | 1.7 | 1.5 |
| 2 | 1.5 | 1.3 | 1.3 | 1.1 |
| 3 | 1.7 | 1.8 | 1.6 | 1.4 |
| 4 | 2.2 | 2.2 | 2.0 | 1.6 |

Wilson [4], on the basis of independent studies, but employing light reflectance methods, instead of light transmission, has also found a linear relationship indicating the applicability of Beers law for low optical densities. Hall's $K_m$ value is based on the assumption that this law holds.

*Unit Value*

To facilitate description of results, we define a unit value as that quantity of light scattering solids producing an *optical density of* 0.01 when measured by light transmission. In our laboratories we call this 1 Coh unit. Thus, a spot giving a light transmission value of 50 per cent corresponding to an optical density of 0.301, which is the logarithm of $\frac{100}{50}$, is 30.1 Coh units.

*Measurement of Optical Density*

While the quantity of particulate matter deposited on a filter can be evaluated by either reflectance measurements or by measurements of light transmission, we prefer light transmission, because the apparatus parts are so inexpensive and the procedures so simple. Furthermore, in contrast with reflectance measurement apparatus, it is unnecessary to specify in fussy detail the characteristics of the apparatus elements and their assembly.

The simplicity is illustrated in Figure 2, where a crude assembly of homemade parts that is entirely adequate for light transmission measurement is shown. The light source is a small 100 watt bulb with a bayonet base of the type available from laboratory supply houses, enclosed in a can with a light orifice in one end. The light sensitive cell and meter indicator is the assembly available as the ordinary foot candle meter employed for measurement of illumination.

A more convenient assembly (though no more accurate) is illustrated in Figure 3 where the light sensitive cell is separated from the indicating microammeter, and the source of illumination is a low cost laboratory lamp. It incorporates a track whereby the position of the lamp is easily adjusted to a suitable distance that will result in a convenient needle deflection on the microammeter.

A measurement is made by positioning a clean area of the filter paper in the holder in front of the lamp. The position of the lamp is then adjusted to give a reading of 100 (or any other convenient value) following which the spot to be evaluated is shifted into position, and the resulting reading recorded as a percentage of that obtained with clean paper.

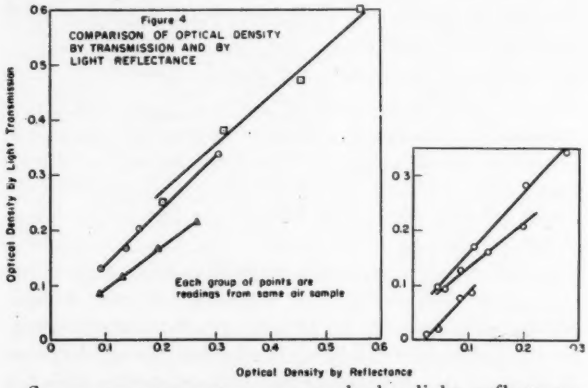


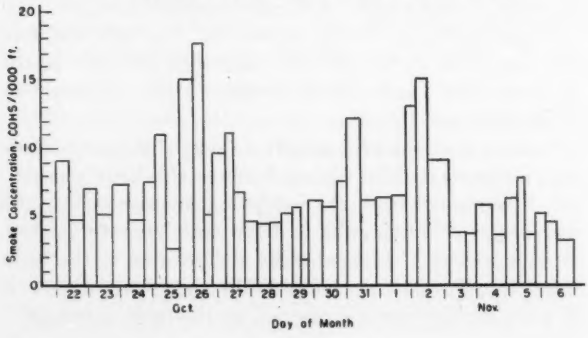
Figure 4
COMPARISON OF OPTICAL DENSITY BY TRANSMISSION AND BY LIGHT REFLECTANCE
Optical Density by Light Transmission
Each group of points are readings from same air sample
Optical Density by Reflectance

Some measurements were made by light reflectance using a Photovolt meter to show the relationship between those data and light transmission values. When optical densities by each method are plotted against each other, a straight line results as shown in Figure 4. The data also indicate that light transmission measurements are more sensitive for light deposits.

*Size of Air Sample and Concentration*

The preceding discussion has been concerned with a description of the quantity of smoke or light scattering solids. In order to express a concentration or intensity, a denominator is required, that is, the size of the air sample. Since the volume of air aspirated through the filter and the area of the filter both determine the intensity of the filter paper stain, it follows that the size of air sample is properly described in linear units of air, not, as might first be supposed, in units of air volume. Thus, 100 cubic feet of air drawn through a circle having an area of 0.1 square feet will give identical results with another sampler aspirating 10 cubic feet of the same air through a circular area of 0.001 square feet. In both cases, the size of sample is 10,000 linear feet of air.

FIG. 5
SMOKE CONCENTRATIONS AT ONE PITTSBURGH LOCATION, SHOWING EFFECTS OF FOREST FIRES DURING FALL OF 1952




We have found it convenient to reduce all results to multiples of 1000 linear feet of air so that the concentration for any time period is described as so many Coh units per 1000 feet of air.

Some measurements of outdoor air obtained at our Pittsburgh laboratory are described in this terminology in Figure 5 and Table II. In terms of subjective impressions of visibility, 1 Coh per thousand feet represents a brilliantly clear Pittsburgh day and 10 Cohs is disagreeably smoky. The forest fires in the fall of 1952 produced some extreme peaks.

The monthly average smoke concentrations given in Table II illustrate how historical records for a locality would be expressed.

TABLE II
MONTHLY AVERAGE CONCENTRATIONS OF HAZE-SMOKE IN OAKLAND SECTION OF PITTSBURGH

| | Concentration: Coh units/1000 ft. | | |
|---|---|---|---|
| | Monthly Average | Maximum for any 2-hour period | Minimum |
| December, 1952 | 6.5 | 9.1 | 1.4 |
| January, 1953 | 3.9 | 10.1 | 1.1 |
| February, 1953 | 3.4 | 9.4 | 1.0 |
| March, 1953 | 2.6 | 7.8 | 0.8 |
| April, 1953 | 2.5 | 9.6 | 0.4 |

*Significance of Units*

It is often suggested as desirable or necessary that the concentration of particulate matter in the atmosphere be expressed in weight units. Indeed, Owens himself produced a calibration for his smoke filter instrument whereby the various stains could be converted into milligrams per cubic meter. This procedure is not only undesirable, but based on a false premise which ignores the fact that different aerosol systems have varying proportions of very large particles, very small in their proportion by numbers, but often a high proportion by bulk or weight. Furthermore, these large particles have no significant power to scatter light but have an overwhelming influence on the weight found in any volume of air since the pollution *effect* of very fine particles is a result of light scattering whether we consider the phenomenon of haze due to such particles in suspension in the atmosphere or whether due to their soiling effect on a ceiling surface. The light transmission or light reflectance measurement is also a quantitative indication of the light scattering potential, an effect of the small particles present. Thus, the physical cause producing the pollution effect is reproduced in the measurement method. In a sense, the light measurement constitutes a particle screen which effectively removes the large particles from the sample due to the facts expressed in the laws of optics.

Furthermore, beyond the question of fundamental error implied, there is no logic in seeking to convert results of optical measurements into weight measurements simply because milligrams and cubic meters are more familiar units. An arbitrary unit of measurement describing light scattering potential, such as the Coh unit referred to above, is every bit as fundamental as is the milligram.

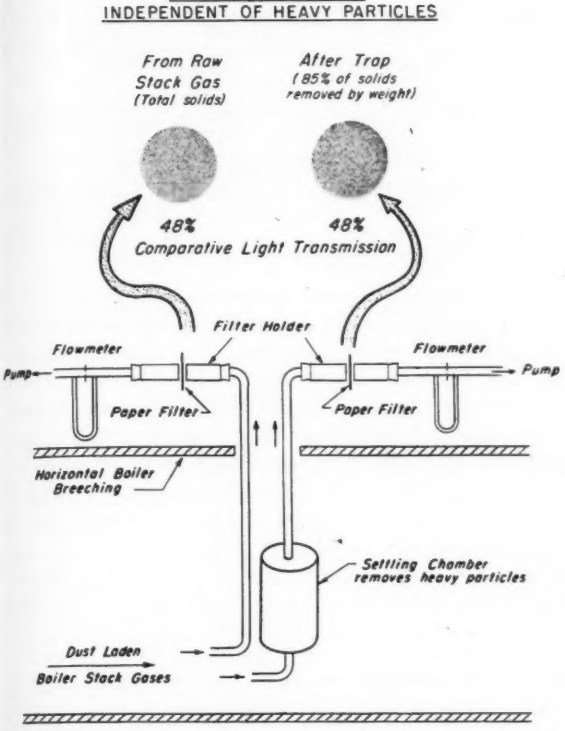



FIG. 6
DEMONSTRATION OF STAINING PROPERTIES
OF DUST LADEN STACK GASES

The standard kilogram is universally referred to by a process of comparison as the standard unit of weight only because of wide acceptance and for no other reason.

*Limitations in Weight Measurements*

The lack of any relationship between concentrations and light scattering potential is dramatically demonstrated by an experiment in which we aspirated through two parallel sampling tubes an equal quantity of polluted stack gases, through each of two filter papers in one train; a gravity trap was arranged ahead of the filter to permit settling out of large particles. Measurements established that 85% by weight of the solids were removed in this trap, yet the density of the filter paper stain, as determined by light transmission, was equal in both cases. This is illustrated in Figure 6.

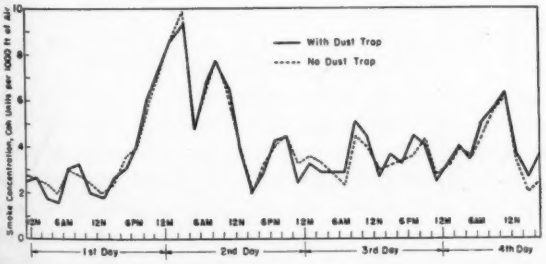



Fig. 7 COMPARISON OF FILTER PAPER SMOKE CONCENTRATIONS BY TWO I.S.I SMOKE SAMPLERS IN PARALLEL, ONE IN STREAM PASSING THROUGH A MARBLE DUST TRAP

In another extended series of measurements, two I.S.I. Automatic Smoke Samplers were operated in parallel for a period of several days. One sampler was permitted to draw air directly from the exterior atmosphere, and in the other the air was caused to pass first through a dust trap which contained a 2-inch thick layer of glass marbles, one half inch in diameter. The cross-sectional dimensions of the trap were such as to result in an average gross velocity of ½ to 1 foot per minute. No determination of the weight percentage removed was made, but there is little doubt that a major fraction of the weight of solids entering were removed. The relative optical densities shown in Figure 7 are not significantly different in spite of the fact that large particles were removed by the trap in one case. This demonstrates strikingly that the heavy particles contribute insignificantly to the light scattering phenomenon.

*Samplers for Smoke and Haze*

Hall's sampler (4) is designed to aspirate air through a circle that is one square inch in area, at a rate of about 0.4 cubic feet per minute, or, as we would prefer to express it, at a rate of 3600 linear feet per hour. Hall employs light reflectance apparatus for the measurement with monochromatic light having a wave length of 400 millimicrons and expresses the results in units he calls $K_m$ value, a unit which includes not only quantity of light scattering solids (by reflectance), but also the quantity of air sampled.

Wilson's apparatus also employs filter paper tape, and he has employed light reflectance for evaluation of quantity of solids deposited in the pores of the filter paper.

*Characteristics of I.S.I. Smoke Sampler*

The I. S. I. Automatic Smoke Sampler has been previously described by us (2, 5) as a sampling instrument differing in principle in no fundamental respect from others, but having some unique mechanical characteristics (See Figure 8). Having in mind the need for an instrument which could be disposed over an area in large numbers for complete coverage in a micrometeorological study, it was designed for maximum simplicity and for production at minimum cost per unit. We also deemed it of major importance that the pump be as nearly silent during operation as possible, thus to simplify the problem of location and 24-hour operation in or near places of habitation.

We originally described its optimum timing cycle to give one sample each 6 hours, but as has been indicated earlier, we now recommend samples not exceding one, two or three hours in duration in order to avoid sample spots of excessive optical density.

The pump employs a slow motion reciprocating diaphram (operating on the principle of the old manual fireplace bellows) and has the air pumping characteristics described in Figure 9. Present models have an initial capacity, aspirating through clean Whatman No. 4 filter paper, of 2.05 c.f.m. Pump capacity is reduced only by 10 to 20 per cent by the end of the two or three hour cycle, depending on the concentration of solids in the atmosphere.

*Procedures for Measurement*

In applying the evaluation procedures described herein, the pump capacity should first be checked by connecting the unit to a suitable gas flow meter, with clean paper in position, and subsequently with paper soiled in use. The average sampling rate is then employed for use in calculating the size of the air sample.

*Automatic smoke filter sampler.*

The sampler is operated on a time cycle which will avoid stains of optical density exceeding about 0.3. With the I.S.I. Automatic Smoke Sampler pumping air at the rate of about 0.25 c.f.m. through a 1 inch diameter circle, this specification is usually met by a cycle of one sample every 2 hours although it can be lengthened to 3 hours in the summer time where domestic smoke is the principal contributor. In winter where concentrations of coal smoke are dense, it may be reduced to a one-hour cycle. Attachment or removal of additional spindles in the periphery of the time rotor permits one to vary the sampling cycle at will. Calculations are illustrated in the following example.

*Example*

Assume measurements with a gas flow meter have established the average air flow rate to be as follows:
Average air flow rate=0.22 cu. ft./min.
Timing spindles are set for 2-hour samples, hence, each sample represents 26.4 cu. ft.
Area of 1 inch sampling circle=$5.45 \times 10^{-3}$ sq. ft.
Then,

$$\text{Air Sample} = \frac{26.4}{5.45 \times 10^{-3}} = 4850 \text{ linear ft. of air.}$$

If a given spot shows a light transmission value of 50% then,

$$\text{Optical Density} = \log \frac{100}{50} = \log 2 = 0.301$$

Since one Coh unit = 0.01, we have 30.1 Coh units and the

$$\text{Concentration} = \frac{30.1}{4.85} = 6.2 \text{ Coh units/1000 ft.}$$

*Determination of Chemical Constituents*

Where micro-analytical methods are available for a particular substance, automatic filter paper samplers can be applied to the measurement of atmosphere concentrations. However, if the purpose is to evaluate health hazards due to human inhalation, the results will be meaningless unless a trap is provided at the instrument inlet to reject large particles. This subject has also been discussed in Reference 7. A suitable trap for connection to the inlet of the I.S.I. sampler which removes particles larger than 5 to 10 microns can be simply assembled from a tin can having a diameter of 6½ to 7 inches, or greater, with a two inch layer of one-half inch marbles supported above the bottom on a screen.

*Measurement of Haze or Smoke Potential in Stack Gases*

The same system of sampling and evaluation is usefully applicable to the evaluation of stack effluents. It is usually impractical to aspirate raw stack gases through the sampler especially if the gases are at elevated temperatures or laden with moisture. A practical arrangement is illustrated in Figure 10 in which a stream of raw stack gases is diluted with fresh air at a fixed rate which is indicated by orifice flow meters in each line. The rate of dilution is selected to reduce the temperature of the

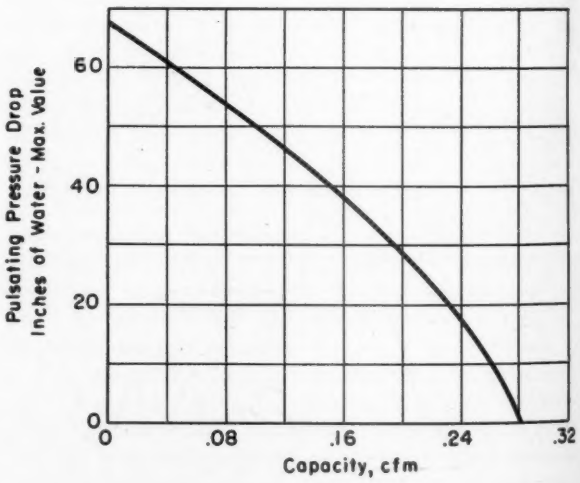



Fig. 9. PRESSURE-VOLUME CHARACTERISTICS OF I.S.I. AUTOMATIC SMOKE FILTER PUMP

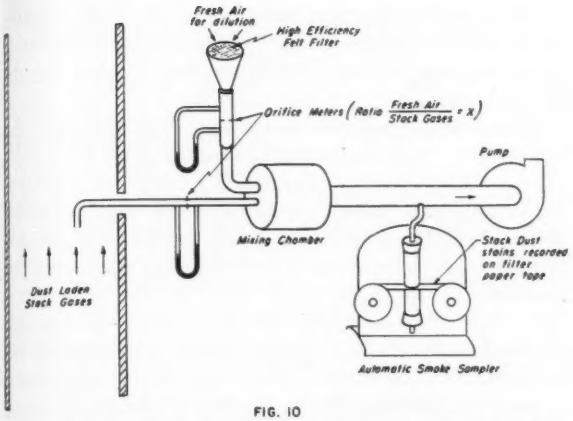

Fresh Air for dilution
High Efficiency Felt Filter
Orifice Meters (Ratio Fresh Air / Stack Gases = x)
Pump
Mixing Chamber
Stack Dust stains recorded on filter paper tape
Dust Laden Stack Gases
Automatic Smoke Sampler

FIG. 10

EQUIPMENT FOR DETERMINING THE STAINING PROPERTIES OF STACK DUSTS

resulting mixture to some convenient low level, e.g., 100-125° F, and the dew point below that of the ambient temperature. A sampling tube to the smoke sampler supplies an aliquot stream to the filter paper. With the I.S.I. instrument the timing cycle can be reduced to any desired frequency.

*Quantitation of Stack Effluents*

The evaluation of smoke concentration is made in exactly the same manner as previously described, incorporating the measured dilution factor into the calculations, the result being expressed as before in Coh units per linear foot of stack gases (It is more convenient here in deriving the concentration to employ the single foot.)

The aggregate effluent rate is, of course, proportional to the total rate of flow of stack gases into the atmosphere, usually expressed in cubic feet per minute. One must, therefore, multiply the concentration in Cohs per foot by gas flow rate in cubic feet per minute.

When this is done, we note the curious fact that such effluent rates are described not as might be supposed in the units Cohs per minute, but rather in the units Cohs-square feet per minute.

*Example*

Suppose that at a dilution of 50:1, a concentration of 0.08 Cohs/foot air is established. Then the original stack gas concentration would be

$$50 \times 0.08 = 4 \text{ Cohs/foot}$$

Next,

Assume the stack gas flow rate is 10,000 cu. ft./min. The product of these two values, then, gives the rate of stack discharge of haze or smoke as follows:

$$4 \times 10{,}000 = 40{,}000 \text{ Coh-ft}^2\text{/min.}$$

The practical validity of this unit can perhaps be better visualized by a supplementary calculation in which one would determine the concentration of smoke at ground level when the given quantity, in the units Coh-ft.$^2$, is dispersed in some specified volume of air, as in the following:

Calculate the smoke concentration that would result when the smoke effluent for one minute from the stack in the preceding example is dispersed in 4 million cubic feet of air.

The smoke effluent for one minute is 40,000 Coh ft.$^2$ This is to be divided by 4 million cu. ft. of air as follows:

$$\frac{40{,}000 \text{ Coh-ft}^2}{4{,}000{,}000 \text{ ft}^3} = 0.01 \text{ Coh units/foot}$$

$$= 10 \text{ Coh units/1000ft.}$$

This calculation illustrates how the units become properly transformed back into those originally employed to describe concentrations at any location in the open air. It will be clear on a little reflection that the geometrical shape of the 4 million cu. ft. of air volume does not in any way modify the result.

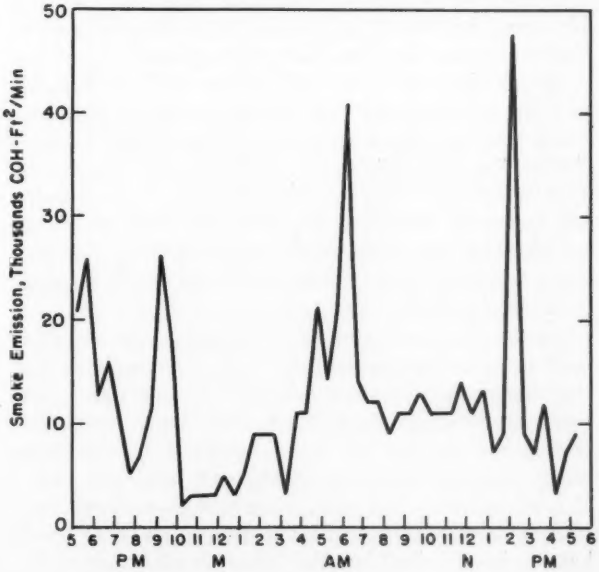
*Illustrative Measurements on Boiler Plant Stack Gases*

Using a simple arrangement like that illustrated in Figure 10, a 24-hour test was made on the stack gases of a coal burning, stoker fired boiler plant. Stack gases were diluted in the ratio 30:1, and the I.S.I. Smoke Sampler was adjusted to give a sample each half hour. The flow of stack gases past the sampling point was 80,000 cu. ft. per minute, and the effluent rates calculated to the units Coh sq. ft./min. as described in the earlier example. No particular significance is attached to any details of this chart since it was produced solely to illustrate the principle we have been discussing.

It will be realized from the earlier discussion that these results describe only the stack output of light-scattering solids (i.e. smoke in this case) and are not related at all to the output of ash, coal and coke particles which would contribute to dust fall. Measurement of the latter must be made by entirely different methods, which are outside the scope of the present report.

FIG. 11

SMOKE EMISSION FROM STACK OF STOKER-FIRED COAL BURNING BOILER PLANT IN THE UNITS COH-FT$^2$/MIN.



*Limitations*

In describing the size of the air sample in linear units as described herein, one can be completely independent in his selection of a filter paper sampler. Air may be sampled at any desired rate using any convenient area of paper.

In the evaluation of the sample, however, the magnitude of the result is dependent on the characteristics of the filter paper (see Table III) and on the particular light measurement method, e.g. light transmission, light reflectance and whether monochromatic light or polychromatic light from a tungsten filament lamp is employed.

TABLE III. Comparison of values obtained on identical air samples when different filter papers are used and when evaluated by light transmission or by light reflectance.

*Optical Densities by Reflectance (R) and by Transmission (T)*

| Run | Faint Spots (a) | | (b) | | (c) | | Dark Spots (d) | | (e) | | (f) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T | R | T | R | T | R | T | R | T | R | T | R |
| E & D 607 | .06 | .04 | .09 | .06 | .08 | .06 | .20 | .14 | .22 | .16 | .35 | .25 |
| Whatman 42 | .05 | .03 | .06 | .05 | .04 | .05 | .13 | .11 | .12 | .14 | .14 | .21 |
| Whatman 52 | .03 | .02 | .04 | .05 | .07 | .04 | .12 | .11 | .16 | .13 | .20 | .19 |
| Whatman 50 | .04 | .03 | .03 | .03 | .02 | .01 | .09 | .11 | .10 | .12 | .14 | .16 |
| Whatman 4 | .05 | .03 | .07 | .04 | .10 | .05 | .16 | .15 | .20 | .14 | .28 | .27 |

It can not be claimed that any one filter paper or any particular light measurement method is fundamentally more correct than another. Therefore, advocacy of a particular procedure must rest on less fundamental criteria. Our selection has been based on the desire to evolve the simplest possible procedure, using the least expensive apparatus.

We selected Whatman No. 4 filter paper because its low resistance to air flow matched the aspirating capacity of the diaphragm pump in our sampler. Also, it is readily available commercially. Incidentally, the data in Table III show, also, that it gives a higher reading for a given smoke quantity than most other filter papers.

In outlining our reasons for selection of light transmission for evaluating the spot samples using the polychromatic light provided by tungsten filament lamp, we have shown the variability to be expected between results by that method and those by reflectance. There is no consistent factor by which results from one method can be transformed into those by the other although, interestingly, results by either method are of somewhat the same order of magnitude.

Just as the description of a building structure giving only its linear dimensions has narrow significance, so with the measurement system described in this paper. The figure describing smoke or haze concentrations employing this method denotes only one air pollution quality of the atmosphere (although one of the most important ones). If other qualities, e.g. color, degree of flocculation, etc., were of interest in particular circumstances, they would have to be described by other dimensional systems.

The work reported here has been a part of the research on air pollution sponsored by the American Iron and Steel Institute with an Advisory Committee headed by Mr. W. O. Everling.

Special acknowledgements are due Dr. Jack Brown, who designed an early model of the sampler; Mr. Ivan Yahn for assembly of the first pump model; Research Appliance Company, Box 413, West View Road, Pittsburgh 19, Pennsylvania, who are responsible for the present improved form of the sampler and who now manufacture it for sale.

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## Petroleum Briefs

—American Petroleum Institute

By 1975, the Census Bureau predicts we will have 193,000,000 people in this country. We'll be driving 65,000,000 automobiles, about one-third more than jam our highways today. The demand for oil and oil products for these cars will be met, as it is today, by the progressive people of the oil industry.

* * *

Within the last 25 years, hydrocarbons from petroleum and natural gas have become a source of raw materials for more than 2,500 different chemical products.

* * *

The lonely wail of the steam locomotive is being drowned out by powerful diesels on modern American railroads. The vibrant diesel horn may not produce the same nostalgic sound as the steam engine's whistle, but it does indicate progress and economy for the American people. Railroads have found that diesel locomotives pay for themselves in three to five years. Officials say they already are saving a half billion dollars a year by switching from steam to diesel locomotives.

# Some Unique Aspects of Air Pollution in Los Angeles

*by* Fred E. Littman and P. L. Magill
Stanford Research Institute, Stanford, California

## I. *Introduction*

The atmosphere over every large community is constantly altered by the everyday home activities of the residents. Many thousands of stoves, furnaces, incinerators, automobiles, and other conveniences contribute alien materials to the air. These materials are augmented by the industries of the area. Whatever the source of contamination, the really critical factor in a community's degree of atmospheric purity is the ability of the air to cleanse itself, relative to the amount of man-made impurity it must dilute or dissipate. To the extent that fresh air from uncontaminated areas does not replace the contaminated air, the community is subjected to the problem of air pollution.

Although many cities daily vent many thousands of tons of impurities into the atmosphere, few are so limited as Los Angeles in ability to safely dispose of aerial waste. The natural weather and geography of the Los Angeles Basin are such that the capability of the air above it to renew itself was exceeded several years ago by the increased quantity of impurities resulting from the phenomenal growth of population and industrial activity in the area. The frequent consequence is an apparently unique type of eye-irritating, plant-damaging air pollution known as "smog."

The purpose of the following discussion is to describe Los Angeles smog as a distinct phenomenon that results from a particular coincidence of related factors. An exhaustive analysis of present knowledge in the field is not possible here, but the data obtained in Los Angeles can be compared with those available for other cities. These data show that the more obvious manifestations of air pollution, such as the thick smoke and heavy dustfall found elsewhere, may obscure the nature of other aspects of the problem. Research in the relatively "clean" city of Los Angeles has necessarily led to an emphasis on less well-known factors. To what extent the knowledge gained in the study of smog reveals an actually unique condition and to what extent it can clarify the problems of areas with other contaminants, less sunshine, and less air stagnation, are questions that need further investigation.

## II. *Meteorological Considerations*

The unusual topographical and meteorological conditions of the Los Angeles area are, by now, well known: it is hemmed in on three sides by mountains that limit the lateral movement of the prevailing sea breeze and funnel it through a few passes. The total air movement averages about 120 miles a day, but, due to the regular changes in direction of the land and sea breezes, some of this movement results only in a shuttling of air masses back and forth across the Basin and is not effective in purging the contaminated air (Figure 1—See Cover).

Of equal importance is the presence of a warm air layer, known as the Pacific inversion, aloft over the California coastal areas. If this air mass drops to 3,000 feet or less—as it does on 280 days of the year—it constitutes an effective lid over the Los Angeles Basin, preventing vertical escape of polluted air. When the long, undisturbed reaction times favored by these conditions coincide with plentiful sunlight and relatively high temperatures, threshold concentrations of noxious materials are quickly exceeded. Ideal conditions then prevail for a variety of reactions of the various contaminants.

The resulting condition—smog—may be characterized as a polluted air mass containing both gaseous and particulate contaminants that cause a reduction of visibility and, frequently, damage to sensitive crops, as well as eye and nose irritation. But here the first significant differences between the smog that occurs in Los Angeles and smog that occurs elsewhere shows up. Los Angeles smog almost invariably occurs under conditions of low relative humidity (60% or lower). The visible part is composed very largely of aqueous, or at least water soluble, droplets, and only to a minor extent of solid particulate matter. These droplets may persist because they contain dissolved inorganic salts, such as nitrates and sulfates, as well as organic compounds.

One of the most distinctive factors of Los Angeles smog is the characteristic pattern of its appearance: a typical smoggy day starts out as a clear, sunny, and warm morning. Several hours after sunrise, usually between 8:00 A.M. and 10:00 A.M., a haze begins to form, becoming denser and more irritating until a peak is reached between 11:00 A.M. and 2:00 P.M. The early afternoon sea breeze, which reaches Los Angeles around noon, and Pasadena at perhaps 2:00 P.M., usually dispels at least part of the smog cloud, pushing it out the passes in the surrounding mountains. The late afternoons are frequently brilliantly clear—but the pattern repeats itself day after day with varying intensity, apparently depending largely on meteorological factors such as the height of the inversion layer, the intensity of the sunlight, and the onset of the sea breeze. Sometimes not all of the pollution is removed, and a portion remains to contribute to the following day's smog. Data for a typical smoggy day are given in Figure 2, which presents visibility, ozone concentration, and wind speed data at Los Angeles.

The existence of large concentrations of ozone (more than 15 pphm) in the atmosphere is one of the best indicators of the existence of a smog condition. The smog effects, as nearly as can be judged subjectively, are about

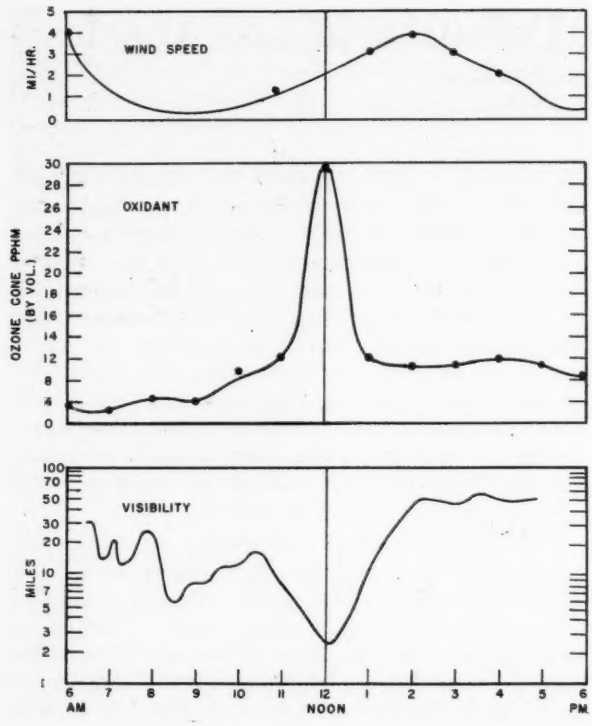


FIG. 2
A TYPICAL SMOGGY DAY IN PASADENA

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proportional to the ozone concentration, in the range between 15 and 50 pphm. Figure 3 shows the occurrence of smog, as indicated by ozone concentrations at three locations throughout the area.

Another of the interesting features in this smog pattern is the simultaneity of the occurrence of smog throughout the Basin as revealed by ozone measurements. It has long been thought, particularly by the inhabitants of such residential areas as Pasadena (1, 2), that smog is something inherited from "bad neighbors" at Los Angeles, whereas the Angelenos blame the industrial areas in the southern parts of the Basin—and particularly the oil refineries—for producing smog, and the sea breeze for bringing it in. Information accumulated by Stanford Research Institute (11) since 1949 throws doubt on this concept, for measurements show that smog formation starts simultaneously from Long Beach to Pasadena, beginning shortly after 8:00 A.M., and tapering off with the arrival of marine air.

It would seem that the formation of smog is primarily a function of available sunlight, acting on accumulated pollution, and that the primary function of the sea breeze is not so much to transport a smog cloud from one place to another, but rather to dissipate it by stirring it up and diluting it, thus lifting the veils of smog first at Los Angeles, then at Pasadena, and so on.

The concept of the simultaneous formation of smog at different places has far-reaching implications, for it requires that the ingredients going into the making of smog be present in the early morning everywhere that smog is formed. Thus, spot source of these smog precursors is ruled out, for there is no time for them to be distributed throughout the valley prior to the onset of smog. To illustrate this more fully, let us look at a map of the area and diagrams of typical wind patterns (Figure 1). As an example, consider a typical sequence of events at Pasadena: after a smoggy day, the sea breeze has swept the air clean, as is indicated by visibilities in excess of 15 miles. Toward evening, the wind direction reverses itself, and the air movement slows down to 1 to 2 miles per hour. Certainly no air from the industrial south can now arrive, as such air currents as there are move toward the south. And in fact, the next morning the air appears just as clear as it did the night before. Soon after sunrise, however, and long before any significant horizontal air movement in the opposite direction begins, a haze starts forming, visibility decreases, and the typical odor and irritation of smog sets in.

Elsewhere in the Los Angeles Basin, the smog also forms at times that bear little relationship to the direction of wind movement, but rather to the time of appearance of the sun. Therefore, the ingredients of smog must have accumulated during the night or early morning hours from many widely dispersed local sources.

This, then, appears to be the meteorological mechanism of smog. But what of its composition and its properties?

## III. COMPOSITION OF SMOG

### A. *Particulate Contaminants*

As mentioned earlier, the smog mass consists of both gaseous and particulate contaminants. Early analyses (3) showed that the particulate phase consisted of some 40 constituents; however, the actual quantity of suspended material, less than 0.3 mg/m³ even on smoggy days (4), was rather low compared to that found in other large communities, and a significant abatement of solid partic-

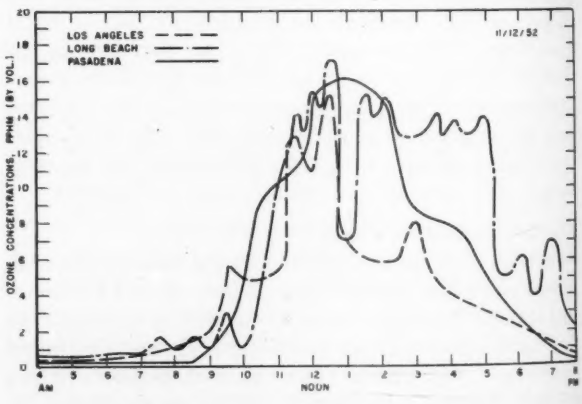


FIG. 3
COMPARISON OF OXIDANT LEVELS AT VARIOUS LOCATIONS

IA-C466-66

ulate matter has recently been achieved through the efforts of the Los Angeles Air Pollution District. The dustfall is compared with other cities in Table I (5).

TABLE I

YEARLY DUSTFALL DATA

| City | Year | Dustfall tons/sq. mile/year |
|---|---|---|
| Baltimore | 1926-28 | 1800 |
| Chicago | 1946 | 782 |
| Cleveland | 1929 | 780 |
| Detroit | 1946 | 678 |
| Pittsburgh | 1952 | 650 |
| Salt Lake City | 1920 | 349 |
| Los Angeles | 1946 | 332 |

In composition, the material collected in Los Angeles was very similar to that found in other places, with one exception (5): it contained a relatively large amount of high-boiling organic constituents. Precipitator samples confirmed this. (A typical slide is shown in Figure 4.) The collected liquid appeared to be miscible with water and immiscible with xylene and contained ammonia, nitrates, and sulfates, as well as a fairly large amount of organic material which charred when heated. On slow evaporation, a "skin" seemed to form over the droplets (Figure 4); this may be the reason for the stability of these droplets under conditions of low relative humidity.

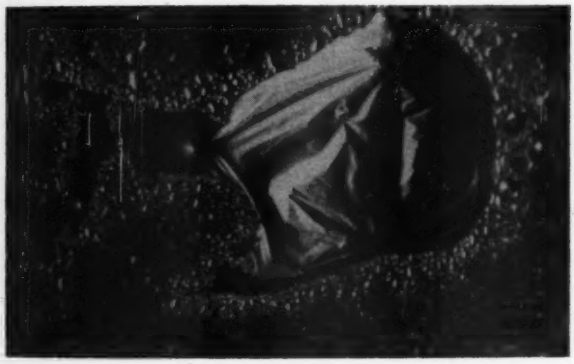

*Fig. 4.—Photomicrograph of electrostatic precipitator sample of smog.*

The composition of the organic portion of the aerosol has been described by Mader (6). It seems to consist of oxidized organic material containing alcohol, aldehyde, and carboxyl groups, as well as some peroxide linkages.

Similar droplets have been observed in stack effluents (Figure 5), regardless of whether the fuel was oil or gas, and in automobile exhaust; they have been collected even from the combustion products of a laboratory Bunsen burner. Although their amount in the atmosphere varies markedly with weather conditions—being less during very clear weather, and greater during either fog or smog—a relatively large number of them appear to be always present in urban atmospheres, where their presence probably accounts for the increasing occurrence of low humidity fogs (7).

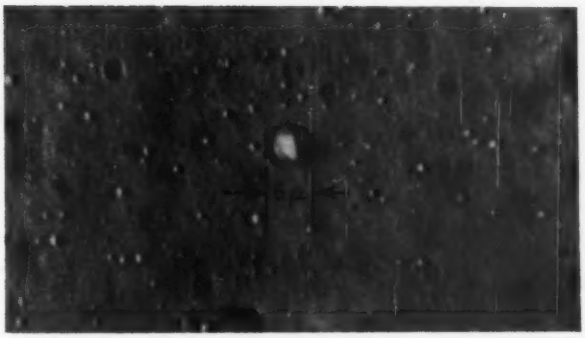

*Fig. 5.—Droplet collected by impactor from oil-burning furnace stack.*

It should be pointed out, perhaps, that these tiny droplets are invisible at their source, but later become a factor in decreasing visibility, apparently because they serve as condensation nuclei and grow in size.

B. *Gaseous Contaminants*

The investigation of gaseous contaminants in the Los Angeles atmosphere showed several equally interesting aspects.

The $SO^2$ level was checked, using continuous Thomas recorders. The over-all level of $SO_2$ in downtown Los Angeles is of the order of 0.05 ppm by volume (8). This compares favorably with other large communities, as is shown in Table II.

TABLE II

SULFUR DIOXIDE LEVEL IN VARIOUS COMMUNITIES

| City | Average $SO_2$ Concentrations (ppm by volume) |
|---|---|
| Chicago | 0.50 |
| St. Louis | 0.25 |
| Pittsburgh | 0.30 |
| Baltimore | 0.07 |
| Cincinnati | 0.06 |
| Los Angeles | 0.05 |

Moreover, there does not seem to be a relationship between the $SO_2$ concentration and smog.

Total oxides of nitrogen ranged in concentration from 0 to 0.25 ppm (by volume) calculated as $NO_2$ (5). These values are again in line with those reported for other communities, and, as in the case of the $SO_2$, there does not seem to be any characteristic change in the concentration during smoggy weather. Analyses for carbon monoxide and dioxide, sulfur trioxide, ammonia, chlorine and fluorine likewise failed to show any significant deviation from the levels found in other urban centers not plagued by smog.

Spot checks for aldehydes indicated concentrations up to about 1 ppm as -CHO (9). The values obtained depended largely on the method of collection: passing the air stream through a bubbler filled with a reagent gave the lowest results; prolonged contact of a trapped air sample with the collecting agent gave higher results; and

an efficient set of packed cold traps yielded the highest results. Apparently only a small fraction (10 to 20%) of the total aldehydes is formaldehyde; the bulk is made up of higher aldehydes. Polarographic analyses showed only traces of unsaturated aldehydes such as acrolein, and no halogenated aldehydes were ever found. The level of aldehyde concentration seems to increase during severe smog attacks.

A large number of organics, essentially hydrocarbons, has been qualitatively identified in the Los Angeles atmosphere by Shepherd (10), using mass spectrometric methods. Among the hydrocarbons identified were acetylene, butane, pentane, benzene, toluene, and xylene. Other hydrocarbons were probably also present, but could not be positively identified. In this class are ethane and propane, olefins from $C_2$ to $C_8$, and other higher hydrocarbons. The spectra of carbon tetrachloride and trichloroethylene were also present. The total quantity of organics has been estimated at 0.2 to 1.1 ppm (as hexene) (8).

The most interesting contaminant found in the Los Angeles atmosphere is ozone, which occurs in concentrations ranging up to 0.5 ppm by volume. This is 10 to 20 times the "normal" concentration at sea level. While the presence in the Los Angeles air of an oxidizing agent exhibiting the general properties of ozone was known earlier, its positive identification was accomplished by Stanford Research Institute (11). This was achieved by a modification of the silica gel concentration technique described by Edgar and Paneth (12), followed by identification of the ultraviolet spectrum of ozone. The occurrence of ozone is closely tied in with the formation of smog, though it is still not clear whether ozone is a cause or a result of the smog-forming reaction. Its level can be used as an objective measure of smogginess in Los Angeles: an increase of ozone concentration is almost invariably accompanied by a corresponding decrease in visibility, due to the formation of a smog cloud. The ozone level is also an excellent indication of plant-damaging pollution. At a sufficiently large concentration, ozone is accompanied by eye irritation. Nevertheless, reduction of visibility and eye irritation are not due to the presence of ozone alone, for ozone itself does not exhibit these properties.

The above constituents have been identified in smog. However, what is the importance of any of these ingredients with respect to the unpleasant properties of smog? And just what are these properties?

## IV. PROPERTIES OF SMOG

### A. *Reduction of Visibility*

The most common aspect of Los Angeles smog is the reduction of visibility which accompanies it. Frequently the normal morning fog never gets a chance to clear up, and instead gradually changes into smog. Visibility decreases, despite a simultaneous decrease of relative humidity that, in the absence of contaminants, would result in disappearance of the fog. A typical smog cloud has a characteristic, flat-topped appearance, which is due to the effect of the temperature inversion. Vertical visibility is generally good, but horizontal visibility may be less than one mile during severe smog. As shown previously, the intensity of a typical smog cloud follows a pattern which appears to be identical with that of the ozone concentration.

The arrival of marine air, propelled by the afternoon sea breeze, generally clears the air, improves visibility, and alleviates smog effects. But occasionally the air remains stagnant for a number of days in a row, and smog gets progressively worse. This occurred, for example, in September-October, 1949, and in October, 1952, when continuous smog remained for several weeks.

### B. *Eye Irritation*

The most annoying feature of smog is the intense eye irritation which sometimes accompanies it. This is not limited to only a few supersensitive individuals, for surveys have shown that over 80% of Los Angeles inhabitants suffer from eye irritation on a severely smoggy day (3). The exact nature of the irritant is not known. Haagen-Smit (13) ascribes the eye-irritating properties to the oxidation products of gasoline, particularly the fraction boiling between 50-80°C. Using pure olefins, the oxidation products of 1-butene were found to be more irritating than other olefins tested. On the basis of intensive studies at Stanford Research Institute, it would appear that the eye irritation could be due to the combined effects of a considerable number of impurities, with aldehydes leading the list. A typical synthetic smog, used during the study of eye irritation in the smog chamber at Palo Alto, had the following composition:

TABLE III

COMPOSITION OF SYNTHETIC SMOG

| | |
|---|---|
| Nitric Acid | 0.5 ppm by wt. calculated as $HNO_3$ |
| Sulfur dioxide | 0.5 ppm by vol. |
| Oil | 0.5 ppm by wt. |
| Sulfur trioxide | 0.2 ppm by wt. |
| Particulate matter (lamp black) | 0.0 ppm by wt. |
| Ozone | 0.35 ppm by wt. |
| Sodium chloride | 0.01 ppm by wt. |
| Gasoline | 10.00 ppm by vol. |

This composition was chosen on the basis of analyses of the Los Angeles air, using those constituents which were considered of importance. The reaction between gasoline and ozone resulted in a variety of oxidized organic compounds, particularly aldehydes.

This mixture smelled somewhat like smog, and was definitely eye-irritating. The omission of any one constituent did not result in a significant reduction of eye irritation, indicating that the combined effect of the mixture's components was responsible for its action.

Measurements and observations made in the city streets appear to demonstrate an excellent correlation be-

tween ozone concentration and eye irritation (Figure 2). Eye irritation appears only if the ozone is above 15 pphm and becomes intense at 30 pphm and higher.

Studies of eye irritation are complicated by the fact that relatively large groups of subjects are required to obtain statistically valid results, as the variability of human reactions in such experiments is very large.

C. *Plant Damage*

One of the most interesting aspects of smog is its effect on plants. This effect was first described by Middleton (14), later elaborated on by A. J. Haagen-Smit (15), Hull and Went (16), Bobrov (17), and also studied by Stanford Research Institute (11).

Middleton noted that crop damage first became apparent in 1944. It consisted of a characteristic silvering of the underside of the leaves of susceptible plants, such as spinach, romaine lettuce, and beets, without top surface damage. Its appearance, as well as the order of sensitivity of the various affected plants, distinguished it from sulfur dioxide damage. Another type of damage noted by Middleton consisted of small necrotic spots on the upper leaf surface; this injury was most prevalent after a heavy fog.

Laboratory experiments initiated by Dr. A. J. Haagen-Smit have demonstrated that at least certain types of smog damage can be duplicated by the use of mixtures of ozone and certain unsaturated hydrocarbons. The maximum damage occurred with olefins boiling in the gasoline range, having a chain length of $C_4$-$C_9$. He postulated that the damaging agent is an intermediate ozonide, since neither the olefins nor the end-products, aldehydes and acids, produce this typical injury.

Investigations at Stanford Research Institute have shown that other types of lesions appear to be due to ozone alone; still others exist that have not been reproduced synthetically. Characteristic smog damage can also be produced by fumigations with mixtures of gasoline and ozone, as well as automobile exhaust and ozone. The evidence indicates, therefore, that certain reaction products of organics, known to be present in the air, are physiologically active, and are responsible for at least some of the smog damage.

Hull and Went described certain effects of air pollution on the general condition of plants, calling attention particularly to growth-stunting by repeated sub-lethal fumigations that caused no visible lesions.

Bobrov described the anatomical changes resulting from fumigations with ozone and hydrocarbons. The typical "silver-leaf" is apparently due to a collapse of the cellular structure. The resulting air spaces cause the silvery appearance.

Careful observation of the vegetation in the Los Angeles Basin by Stanford Research Institute plant experts have confirmed that there are indeed several types of injury to sensitive plants which can be definitely ascribed to air-borne pollution. This was ascertained also by comparing test plants grown in unprotected and in protected greenhouses; the latter received air filtered through activated charcoal, which appears to remove all plant-damaging agents.

The plants most affected were found to be spinach, endive, romaine lettuce, beets, and radishes. There are several typical injuries for each plant.

For example, on spinach the following types of injury occur after an attack of smog: (a) A deep seated silvering on the lower surface, often accompanied by a brown necrosis. (b) An over-all burning of the leaf, resulting in a slight chlorosis, which gives the leaf a "cooked" appearance. This usually develops into a brown necrosis of the leaf, frequently leaving the veins green. No silvering accompanies this type of injury. (c) A whitish glazing of the top surface of the leaf, sometimes extending through the leaf tissues, resulting eventually in a severe chlorosis. No lower surface silvering has been observed on such leaves.

On endive the most common injury is a burning which gives the leaves a cooked appearance. This usually develops into brown necrosis of the tissue, without affecting the veins. Another type of injury is a whitish burn on either the lower or upper surface. Still another type looks like the silvering on spinach; bronze punctate areas on the upper leaf surface, developing into brown necrotic spots, are also common.

On romaine lettuce various shades of bronzing on the lower surface are most common. In the early stages this injury is very shiny; eventually it develops into a brown necrosis. Other types of injury include a "cooked green" appearance, usually clear through the leaf, also changing into a tan necrosis. Deep-seated silvering on the lower leaf surface as well as a whitish glaze on the upper surface also occurs.

On beet leaves there may be a silvering on the lower surface, as well as a "cooked" appearance, beige in color, without any silvering. A whitish top surface glazing, as well as a distinct type of reddish burning on either surface are fairly common. Sometimes reddish punctate markings developing into tan necrosis are found on either surface.

On radish leaves both a top surface silvering and a dull white burn may occur. Light silvering on the lower leaf surface, as well as bleaching of the whole leaf developing into necrosis, have also been observed.

V. *Sources of Pollution*

An intensive, five-year-long search has failed to reveal any sources of ready-made smog, at least with regard to its eye-irritating and plant-damaging aspects.

True, any emission of smoke or fumes contributes to the general haziness of the area, but much progress has been made during the past few years in removing these sources of air pollution. Similarly, the emission of sulfur dioxide has been cut in half, principally by the installation of sulfur-recovery equipment at the refineries (8). These improvements were achieved largely through the efforts of the Los Angeles County Air Pollution District. Yet, it is claimed by many, smog has not decreased in either frequency or intensity.

The emission of particulate solids from these industrial sources is essentially uniform throughout the day, and while they undoubtedly provide a "background" haziness, they do not fit the peculiar diurnal pattern of smogginess described earlier—for even the daily fluctuations of the height of the inversion layer are in the opposite direction. The "lid" being highest around noon, when smog is at its worst. Therefore, the increase of smog is not just due to a mechanical concentration of existing pollution.

The conclusion seems inevitable that much of the smog is formed by reactions in the atmosphere, rather than being vented into it. (8)

The implications of this conclusion are rather formidable, for it is now necessary to re-evaluate all emissions into the atmosphere not on the basis of their obnoxious characteristics as emitted, but in the light of their potential changes through reactions in the atmosphere.

The sources of this newly recognized type of pollution are many, and most of them are inextricably tied up with our way of life. In the Los Angeles area, almost 50,000 tons of materials are burned daily: fuel oil and gas, rubbish, and gasoline. The incomplete combustion of these products results in the release of some 1,600 tons of organics, including many reactive—and therefore potentially nuisance-creating—chemicals, such as aldehydes, olefins, branch chain hydrocarbons and others. Recent investigations indicate that about 850 tons of organics are released by automobiles alone, while industrial operations supply 300-400 additional tons of organics. Also to be considered are the evaporation losses of hydrocarbons.

The origin of ozone, one of the important contaminants, is still not entirely explained: Haagen-Smit (13) postulates its formation as a by-product of the photochemical oxidation of branch-chain hydrocarbons in the presence of nitrogen dioxide which acts as a light absorber. Despite the fact that there has been some evidence indicating the presence of ozone in unpolluted areas, indications are that most of the ozone is formed by a photochemical reaction in the Los Angeles Basin rather than being brought in by a meteorological mechanism, but the nature of this reaction still remains uncertain.

Thus, any organic or inorganic material capable of undergoing changes and reacting with other materials becomes of importance. Sulfur dioxide and nitrogen dioxide are present at apparently insignificant levels. But how significant are the reaction products that result from their interaction with other seemingly unimportant and certainly non-irritating materials? Gasoline vapors by themselves are harmless in the low concentrations that occur in the atmosphere—but how harmless are their oxidation products? If harmful products are formed, what are they? Or take car exhaust. Not the blue smoke screen emitted by an "oil-burner," but the clean, all-but-invisible exhaust of a modern engine in good repair. Recent investigations have shown that even this invisible exhaust consists up to 1% of organic materials. This corresponds to 5 to 10% of the amount of gasoline burned and adds up to a considerable total. Moreover, the car exhaust contains large amounts of nitrogen oxides, suspected of catalyzing many reactions. The effluent from any other combustion process also contains partially oxidized organic constituents, as well as relatively large amounts of nitrogen dioxides.

The most striking property of these materials is that they are all invisible gases, undetected by the usual methods of pollution control, and harmless by normal standards. Yet, after a few hours in the open atmosphere, they may produce an irritating, damaging smog by their interaction.

VI. *Summary*

We find ourselves confronted with a new type of air pollution problem: it no longer suffices to control the emission of visible particulate matter and obvious sources of odor and irritation, for under certain conditions even the harmless, invisible products of our everyday activities can be changed into smog.

Much remains to be learned about the mechanism of these reactions.

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# Some Problems Encountered in Sampling Open Hearth Stacks

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A number of problems are encountered, in open hearth sampling, due to conditions inherent with basic open hearth furnace operations. A summary of some of these conditions will be presented. The summary will, in turn, be followed by a description of a typical sampling procedure, pointing out the specific problems introduced by these conditions.

I. Stack Conditions

A. The moisture content of the open hearth stack gases is about 7-8% by volume with a dew point in the neighborhood of 100°F. This necessitates heating portions of the sampling train to prevent undesired condensation from occuring in the equipment.

B. Temperatures, in the stack at the sampling point, are approximately 1100°F without a waste heat boiler, and approximately 500°F with a waste heat boiler. This necessitates selection of equipment to withstand thermal failure.

C. The presence of an oxidizing atmosphere at elevated temperatures introduces the problem of corrosion. The major gaseous constituents present in the stack are:

| *Constituent* | *Percent* |
|---|---|
| $CO_2$ | 8-9% |
| $O_2$ | 8-9% |
| $SO_2$ | 2-5 ppm |
| $SO_3$ | 100-200 ppm |
| $H_2O$ | 7-8% |
| $N_2$ | approximate balance |

Erroneous sampling data will result unless the equipment is constructed of material which will withstand corrosion.

D. The particulate loading of the gases varies throughout the heat; a factor which must be taken into consideration when taking a sample. The loading varies from 0.5 to 2.5 grains per standard cubic foot with a maximum loading occuring during the ore boil. Particle size ranges normally from less than 0.5 to 3 microns with material from 2 to 3 millimeters being discharged during the flue blowing period. The major constituent is iron. No analysis is presented here as the constituents are generally common to all basic open hearths. Particulate build-up on sampling equipment due to impaction often results in fouling of equipment.

II. Sampling Procedure

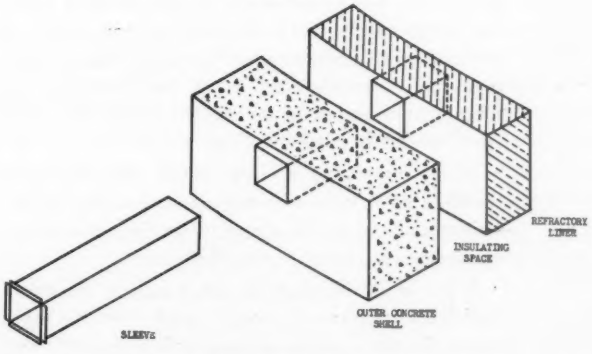
A. Standard procedure is to sample at a location ten stack diameters away from the nearest obstruction. This should permit sampling from an undisturbed gas flow pattern in the stack. Our sampling locations were positioned at this point on nine feet inside diameter stacks. Since the stack inside diameter decreases with height, the average inside diameter was used to choose the sampling location.

At the ten stack diameter level, the flow was still quite turbulent (due to entry of gases and steps in stack liner); however, graphic integration easily provided an average velocity.

A distorted traverse is obtained when the sampling location is not far enough up the stack. When a location even lower down the stack is chosen, the flow on one side will actually be negative. Reverse flow of this type is quite difficult to handle during sampling and equally difficult to graphically integrate for total flow.

B. *Preparation of Sampling Location.* The open hearth stacks, at the Kaiser Steel Corporation, are constructed with an outer shell of reinforced concrete, an insulating space, and an inner refractory liner. When the furnace is down at the end of a campaign, the liner will cool and contract, resulting in a two to three inch drop with respect to the outside shell. Because of this expansion and contraction, it is important that holes be cut in the stack when the furnace is hot and in normal operation. Since the stack operates under a negative pressure of slightly less than one inch of water, infiltration of air through the sampling holes and the air space between the liner and shell will result. This draft will prevent accurate veloc-

Figure 1




SCHEMATIC OF STACK HOLES AND SLEEVE

ity and sampling determinations near the inner wall and should be prevented in some manner, as with a metal sleeve. (Figure 1.)

C. *Velocity Traverses.* It is desirable to ascertain the average velocity of the stack gases before actual sampling. This data will assist in choosing the proper size sampling nozzle, the sample size, and the position to place the sampling nozzle across the diameter of the stack. There are several devices on the market for determining the velocity of gas streams. A vane type anemometer cannot be used due to the high temperature and particulate loading. The separate impact tube and static tap device is unwieldy and does not provide desired results. The pitot tube appears to be best suited for open hearth work. The sixteen foot "Collins" pitot tube, used by the authors, is constructed from a one inch tube to impart rigidity. (Figure 2.) Pitot tubes have constants for velocity calculations which should be obtained from the manufacturer or a calibration will be necessary. The "Collins" tube constant is 0.707, making the formula for the velocity,

$$V = 0.707\sqrt{2gh}$$

The Western Precipitation Corporation (1) manufactures "standard" pitot tubes with a constant of 1.00 and "Type S" pitot tubes with a constant of 0.85. These are adequate for velocities up to 50 feet per second.

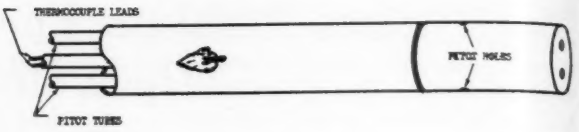
Either of these pitot tubes is satisfactory; however, the "Collins" being a straight tube requires a smaller entrance hole making it more universally applicable.

A standard 18-8 stainless steel is quite satisfactory for the construction of the pitot tube. There will be visible corrosion (surface oxidation) at 1100°F, but the strength is not seriously impaired.

A chromel-alumel thermocouple with its bimetal end emerging three inches back from the pitot holes was installed within the one inch tube. The temperature was determined by conversion of the millivolt values read with a temperature compensated potentiometer. With this combination, temperature and velocity traverses could be made simultaneously. (Figure 2.)

When traversing a large stack, the one inch stainless steel tube will sag somewhat due to its weight and the elevated temperatures; however, it can be easily straightened while hot.

A device for holding the pitot tube is desirable during the traverse. A work bench with a simple superstructure, incorporating roller guides, was used for this purpose. (Figure 3.)



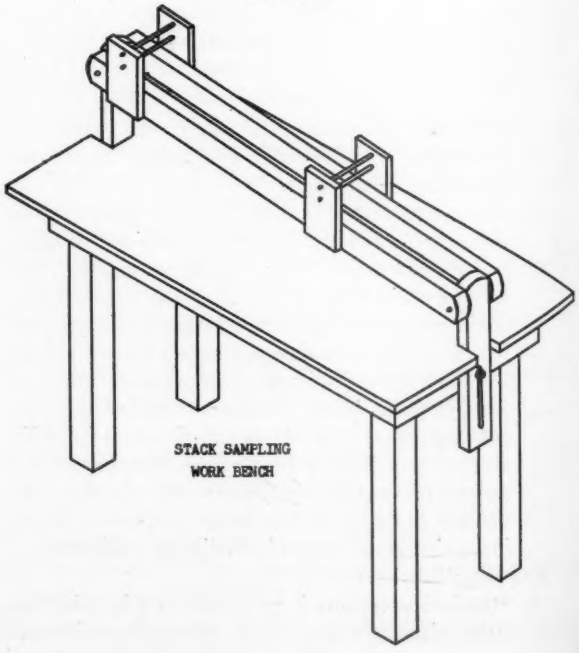

PITOT TUBE-THERMOCOUPLE COMBINATION

FIGURE 2

The equipment required for measuring the pressure head of the pitot tube should have a range of 0.00 to 0.25 inch of water. A convenient device for this is an inclined draft gauge manufactured by Dwyer (2) scaled in 0.005 inch of water. If greater accuracy is desired, an Ellison draft gauge graduated in 0.001 inch of water can be used.

For velocity calculations, it is necessary to know the stack gas density; therefore, the composition of the gas must be known as well as its temperature and pressure. The temperature is obtained by the combination pitot tube-thermocouple mentioned above. Stack pressure can be obtained with a simple "U" tube manometer or an inclined draft gauge with a range of 0.0 to 1.5 inches of water. The gas analysis for CO, $CO_2$, and $O_2$ can be obtained with sufficient accuracy by the Orsat method using a Hays Analyzer. A more complete and accurate gas analysis is considered spurious

FIGURE 3



due to the small difference that would be effected in the calculated density.

The determination of the percent water in the stack gas provided some difficulty since a simple, rapid and instantaneous method was desired. Three methods were tried before a suitable one was adopted.

1. Weighing drying tubes (calcium chloride-calcium sulfate) after passing a known volume of stack gases through them.
2. Measurement of condensate removed from stack gases by cooling.
3. Taking wet and dry bulb temperature readings of the stack gases above the dew point.

A comparison of the results obtained by the three methods is given in Table I. These values are per cent by volume and indicate the *extremes* of numerous samples taken over different portions of the heat.

TABLE I.

Per cent by Volume

| *Calcium Chloride* | *Condensation* | *Psychrometric Charts* |
|---|---|---|
| 7.8-8.4 | 6.2-8.9 | 6.3-9.2 |

The wet-dry bulb method proved quite satisfactory. The assumption was made that the psychrometric charts for air and water applied to stack gases. This assumption was found to hold true within the required accuracy for further calculations. It is interesting to note that the stack gas density is practically identical with that of air.

The minimum manpower required to obtain velocity traverses is a crew of three. With three men, two men would be at the stack sampling location on the roof making traverses and analyses while the third man would be on the charging floor recording pertinent data which can be used for material balances, combustion calculations, or to show the relationship between furnace additions and stack gas flows or emissions. Communication between the two positions is made by a temporary telephone hook-up. The floor man also notifies the roof crew of any operations or additions which will cause a change in the stack gas flow or particulate loading, such as hot metal additions, ore additions, limestone additions, blowing out the flues, tapping, etc. These occurrences should be covered by at least one complete traverse.

Figure 4 shows a result which might occur when the pitot tube holes become plugged by the heavy particulate emission from one of the above additions. It can be seen that the pitot holes were apparently reopened by the vibration incorporated in the traverse. Because this sudden drop in velocity occurred at the exact time of an ore addition, it was thought to be a characteristic feature of such an addition; however, it has since been proven differently.

D. Calculations

1. Velocity and flow calculations are comparatively simple, but quite lengthy. All factors were simplified and the calculations set up in a stepwise manner which could be followed by technicians.

   With the aid of the charging floor data, the heat was broken down into seven sub-divisions:

   (a) Tap and fettling
   (b) Charging
   (c) Meltdown
   (d) Hot metal
   (e) Flush and ore boil
   (f) Lime boil
   (g) Working

   Calculations were made over each sub-division as well as over the entire heat.

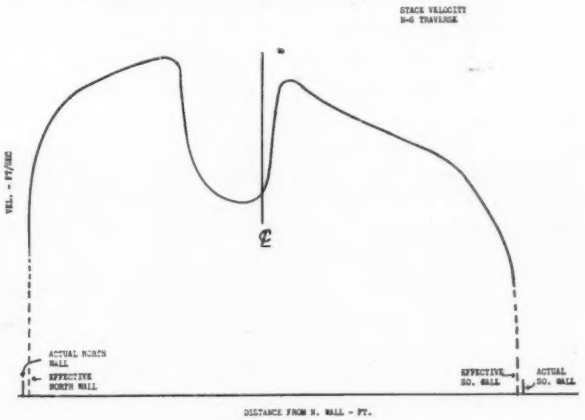



FIGURE 4

The density of the stack gases was calculated by the standard method. It was assumed that the stack gases behaved as ideal gases. This is not strictly valid; however, for the existing conditions it will give results of sufficient accuracy. The analysis of the gases is required in percentages. Summing the product of the molecular weight of each gaseous constituent and its mole fraction will give the weight of a mole of the gases, which when divided by the molal volume (the volume occupied by 1 mole of a gas) gives the density of the gaseous mixture.

The basic equation for the velocity is:

$$V = K\sqrt{2gh}\ (\text{ft./sec})$$

The pressure head, h, is derived from the draft gauge readings, H, in inches of water by suitable conversion factors as:

$$h = \frac{d_{H_2O}}{d_{gas}} \quad \frac{H}{12}\ (\text{ft})$$

The angular traverse board method (1) of point location within the stack is not applicable in open hearth work, due to the thickness of the stack shell, air space, and liner.

The velocity calculated from the above equation is a point velocity and cannot be used to calculate the gas flow rate. An average velocity is necessary for this calculation. For this purpose, equi-area concentric rings must be chosen across the cross-section of the stack. Western Precipitation Corporation (1) has a list of values at which each of these zones occur. This table is for stacks of even dimensions in inches and will require further computations to apply to open hearth stacks. For determining the average velocity, it is not necessary to know the extremities of the equi-area rings, but only the weighted center of each ring. A convenient formula for determining these points with respect to their distance from the effective wall is:

$$d = \frac{D}{2}\left(1 - \sqrt{\frac{2j-1}{2n}}\right)$$

The distances determined from the above equation are located on the velocity versus stack diameter plot, and the arithmetic average of the corresponding velocities represents the average velocity in the stack.

The gas flow rate is the product of the average velocity and *effective* area of flow at the sampling location. The difference between the actual and effective radius of a stack is the thickness of the build-up on the inner surface of the liner and must be taken into account when calculating the effective area of flow.

E. Sampling Rate

For accurate work a sampling nozzle must be used which will permit isokinetic sampling. Such a device is shown in Lapple's work (3). Several other devices appear in the A.S.M.E. Power Test Codes, P.T.C. 21, 1941.

The effect of non-isokinetic sampling is shown by Zimmerman (4), Caldwell (5), and Fahrenbach (6). If the sampling velocity is too high, the particulate sample will contain a lower concentration of particulate material than the main stream and with a greater percentage of fine particles. With a lower sampling velocity, the reverse is true.

The sampling rate of one c.f.m. appears to be adequate for open hearth stack sampling. With stack gas velocities of approximately 20 ft/sec, this sampling rate permits a sampling nozzle size of about ½" inside diameter. Sampling at less than one c.f.m. with a smaller nozzle is likely to cause plugging by particulate impaction as noted in the literature (7).

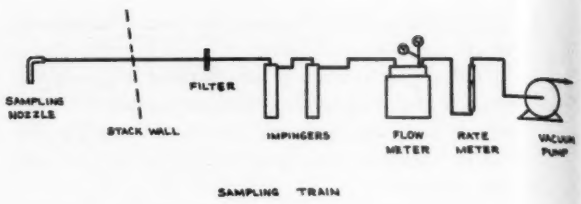



FIGURE 5

F. Sample size

The sample size will depend upon the type of equipment used and the requirements for accurate analyses.

The type of results required must be considered in selecting the sample size. If an average analysis over the entire heat is desired, as large a sample as possible should be taken, limited only by the capacity of the particulate collecting device. On the other hand, if a breakdown analysis of each portion of the heat is desired, the sample size should be governed by the time interval involved, the capacity of the collecting device, and the accuracy of the analytical procedures when dealing with small amounts of material. A larger number of samples is required, for statistical purposes, when the heat is broken down into small units.

G. Sampling Equipment

A typical flow sheet for a sampling train might consist of the items in Figure 5. Many variations of this train may be made.

The 18-8 austenitic type stainless steels have long been considered the best material for constructing nozzles, probes, and other items for sampling. Corrosion is severe on this type steel when used in an open hearth stack at temperatures between 750°F and 1500°F (8), unless the material has been stabilized with titanium or columbium, as in AISI types 321 or 347. Even then, the material has been found wanting in some respects.

A series of tests were run on various types of metals from which it appears that AISI type 321 had the least oxidation and scaling of all materials tested. Generally speaking, this material should be satisfactory for open hearth sampling; however, for extensive work at elevated temperatures, it is felt that a sampling probe of vitrified alumina would be more satisfactory than any of the metals mentioned.

Two general types of sampling nozzles are found in the literature, namely, the standard nozzle and the isokinetic or "null" type nozzle. Figure 5 shows a standard nozzle which requires the use of a flow rate meter to establish isokinetic sampling. Isokinetic sampling requires, of course, that the gas velocity in the mouth of the sampling nozzle be equal to the gas velocity at the sampling point.

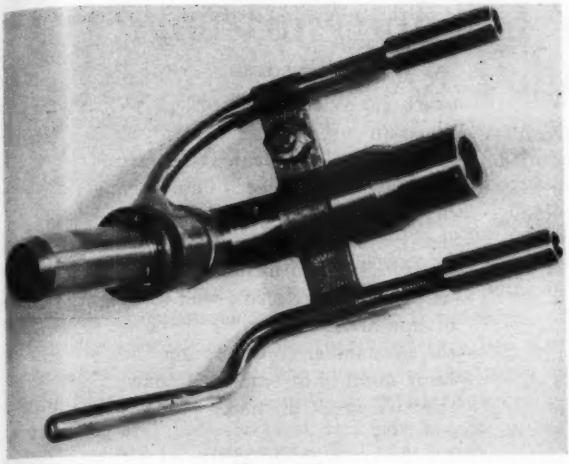


FIGURE 6

Figure 6 shows an isokinetic nozzle designed by the authors. If an isokinetic nozzle is used, the flow rate meter can be eliminated from the train. This type of nozzle requires the use of a very sensitive manometer (9). With a stack gas velocity of 20 f.p.s., calculations show that a movement of 0.003 inch of water must be detectable in order to keep the velocities in the nozzle and stack within 5% of each other. The literature on the Whalen gage (9) indicates the observable accuracy of the gage to be about 0.00008 inch of water.

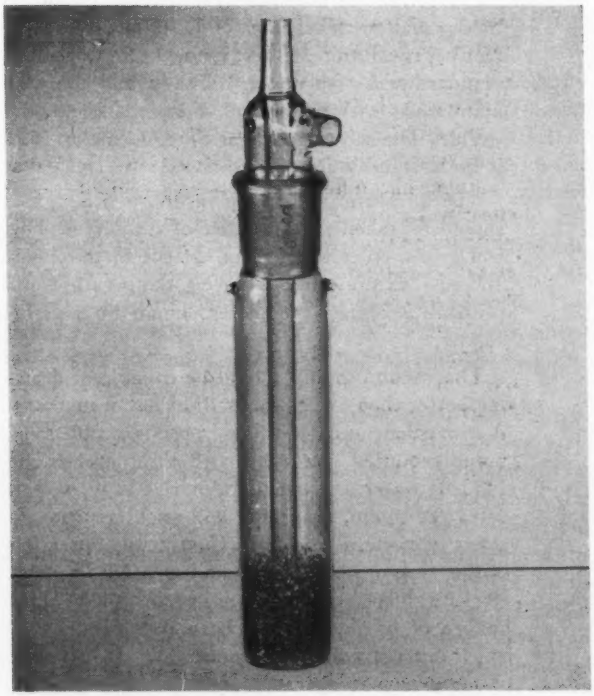
Figure 7 shows six of the particulate filtering devices tried. Each has its advantages and disadvantages.

FIGURE 7

The glass wool filter does not conveniently lend itself to chemical analysis, but it does provide a good filtering medium.

The pressure drop through filter paper is relatively high, and the papers are easily ruptured when wet. The papers do not interfere with the analyses except by adsorption of small amounts of gaseous materials from the stack gases. The three units at the bottom of Figure 7 are electrostatic precipitators designed by the authors. The unit to the left incorporates a single end support discharge rod which shorted out due to excessive vibration. The center unit has double end supports which solved the vibration problem; however, the total dust collectable by this unit was low due to blow-off of the collected material. The tapered unit also has a double end supported discharge rod with the advantage of a larger collecting capacity and consequent reduction in blow-off. Possible changes in chemical composition of the stack gases and particulate matter by the ozone and oxides of nitrogen generated by the high voltage poses a disadvantage. A check on the sulfur showed no significant change from $SO_2$ to $SO_3$, but further studies will be necessary to determine actual amounts. Further, there is always the possibility of blow-off from sparking or power failure. The low pressure drop through the unit is an advantage.

FIGURE 8



A means of heating any filtering device is mandatory (10). If water is allowed to condense, selective removal of gaseous constituents will occur by reason of their solubilities in water, thus separation of the gases from the solids cannot be made.

Several types of gas scrubbing devices are available on the market. One of the more popular units

is the Greenburg-Smith impinger (11) or a variation. (Figure 8) This unit requires the addition of glass beads for effective gas scrubbing action. In addition to the lack of durability on the part of the glass, it is attacked by some of the gaseous compounds in open hearth stack effluents. If accurate analyses of gaseous compounds of silicon are to be made, glass becomes entirely unsuitable. To meet this problem, the impingers may be made of Monel. Gas dispersion tubes with sintered Monel discs were used to introduce the gas as fine bubbles into the scrubbing solution, but the pressure drop through the disc was too great. Good scrubbing action might be achieved using a sintered disc with larger openings having a lower pressure drop. The Monel impingers have Monel wire mesh immersed in the scrubbing solution to promote more effective gas scrubbing. The impingers are conveniently placed in a case which provides an ice water bath for more efficient scrubbing and less water carry over.

The gas meter must be able to withstand a vacuum of several inches of mercury. Aluminum construction is preferable for easier mobility. Sweep dials with readings of 1, 10, and 100 cubic feet per revolution are best for accurate work. The standard wet test meter is heavy and must be maintained with water and, therefore, is not desirable. The dry diaphragm Sprague meter (12) is quite suitable for this work.

The pressure and temperature of the gases should be taken at the outlet of the meter. This will give a truer temperature of the metered gas. In order to prevent fluctuating temperature and pressure readings, the meter should be well insulated.

The vacuum pump should be capable of drawing better than one c.f.m. at 10 inches of mercury. A convenient unit for this purpose is a vane type pump mounted integrally with the motor frame (13). If water or particulate matter is allowed to enter the pump, the vanes will stick resulting in a loss of vacuum and flow. Continuous operation of this type of pump is not advisable until a more efficient lubricating system is installed. This change of lubrication has been developed (14), but is not yet available commercially. If this type of pump is not operated continuously for more than a three hour period, the standard lubricating system will suffice.

A needle valve is quite desirable on the inlet side of the pump for sensitive adjustment of the sampling rate.

### Symbols

| | |
|---|---|
| V | —stack gas velocity, ft/sec |
| K | —constant |
| g | —gravitational constant, ft/sec/sec |
| h | —pressure head in feet of fluid flowing |
| $d_{H_2O}$ | —density of water, lbs/ft$^3$ |
| $d_{gas}$ | —density of stack gases, lbs/ft$^3$ |
| H | —pressure head in inches of water |
| d | —distance from effective wall to weighted center of equi-area zone - ft. |
| j | —the area under consideration |
| n | —total number of equi-area zones |
| D | —effective stack diameter |

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# Wind Direction and Velocity Instrumentation For Air Pollution Diagnosis

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The automatic, continuous analysis and recording of significant atmospheric pollutants, together with the prevailing meteorology, are essential to an understanding of even relatively uncomplicated air pollution problems, as well as the complex situations that exist in urban and highly industrialized areas. The purpose of this paper is to point out the desirability and advantages of recording the chemical and meteorological data side by side on the same chart, and to suggest means for accomplishing this end.

Instrumentation in air pollution is still in its infancy, though a few pollutants can be measured instrumentally in a fairly satisfactory manner, notably sulfur dioxide and other sulfur-containing gases and also the oxidants in the atmosphere. Aerosols present a more complex problem, but an instrument based on light scattering may soon be available for recording the concentration of the particles *in situ*. There is urgent need for instrumentation in the aerosol field and much study is presently being devoted to it.

It is to be noted that these instruments are not specific for a particular compound in each case, but rather they measure groups of compounds of similar properties. For example, the sulfur dioxide "autometer" measures the more soluble acid gases which have appreciable electrical conductivity in aqueous solution. Soluble alkaline gases like ammonia can also be measured. But the simultaneous presence of soluble acid and alkaline constituents in the atmosphere, so far as that is possible, would necessarily complicate the interpretation of the conductivity reading. Slightly soluble gases like hydrogen sulfide, mercaptans and chlorinated compounds affect the instrument only slightly or not at all. However, they can be readily burned to sulfur dioxide and hydrogen chloride and recorded. The "titrilog" on the other hand, measures reducing gases like sulfur dioxide, hydrogen sulfide, mercaptans, and certain organic compounds, to the extent that they are dissolvable in water and oxidizable by bromine. Presumably the simultaneous presence of powerful oxidizing compounds in the atmosphere would reduce to some extent the response of the "titrilog" to these reducing substances. The oxidant recorder of Stanford Research Institute measures ozone, oxonides and peroxidic compounds. Again the simultaneous presence of reducing gases would evidently cause low results.

In spite of their limitations these instruments have great utility in air pollution work. In a comparative study of the titrilog and the autometer in Los Angeles the two instruments gave concordant records a large part of the time, but they diverged noticeably at certain times. Katz states that the autometer readings in the Detroit-Windsor area represent at least 80-90 percent of the total sulfur dioxide as determined by the iodine method. In view of the fact that sulfur dioxide arises from the combustion of fuels and is, therefore, a measurable pollutant that rises and falls with the general pollution level, its measurement should be useful regardless of its relative importance in the pollution mixture. Likewise it has been shown in the Los Angeles area, that the oxidant recordings are closely correlated with the smog intensity both as regards visibility and eye-irritating properties.

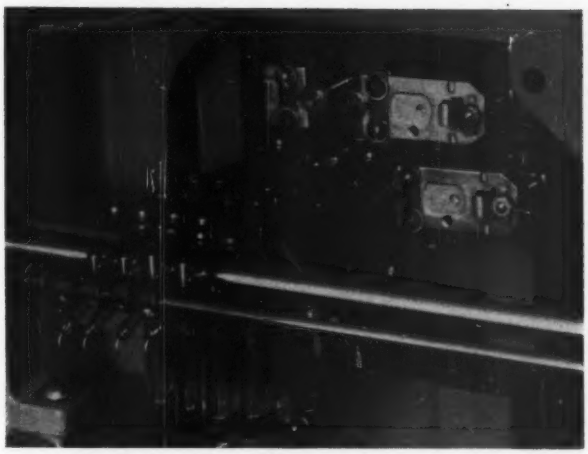

*Fig. 1.—Four pens for recording wind direction, mounted in a sulfur dioxide recorder.*

Meteorological factors play a major role in atmospheric pollution. The dispersing power of the atmosphere may vary from time to time over a range of a thousandfold or more. It is, therefore, important to have a record of the principal meteorological variables that affect dispersion, both for an understanding of the pollution records and for an indication of the probable onset of favorable or unfavorable conditions. Such a record might also be useful as an indication of the source of the pollution, though in a complex environment a number of records might be necessary for this purpose.

The principal meteorological factors that need to be measured are wind direction, wind velocity and turbulence. Other useful factors would be air temperature, lapse rate and insolation. Fortunately the wind factors are readily measured and recorded on any strip chart recorder without interfering with the operation of the recorder. Temperature and sunshine measurements would require special recorders. As a matter of convenience, it is helpful

to superimpose the wind record on the pollutant record. This avoids the necessity of handling two records at once with possible errors in synchronizing them. Further, the relationships are obvious at a glance. Other advantages suggest themselves, such as reduced cost of equipment and fewer records to store. No significant disadvantages have been noted.

Several schemes have been employed for recording wind velocity and direction on the strip chart recorder. Velocity requires merely a pen-carrying relay which makes a "pip" on the chart from contacts on a three-cup anemometer, with each mile or fractional mile of wind travel. It is doubtful if more elaborate velocity recording than this would be justified, though a complete record of the instantaneous velocity with all its fluctuations could readily be obtained, using a bridled-cup anemometer and Selsyn motor transmission, similar to that described later for direction recording. In this case the fluctuations of velocity could be summated, giving a measure of the velocity turbulence.

Well-serviced three-cup anemometers are sensitive to wind velocities down to 1-2 miles per hour. This is probably adequate for most purposes. If lower wind speeds are needed a special anemometer, like that of Beckman and Whitley (5) would be required.

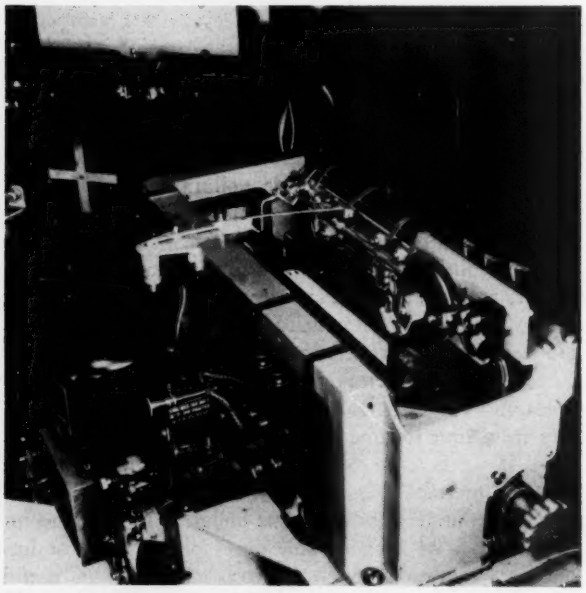

*Fig. 2.—Interior of recorder showing how the pens are mounted. They are automatically lifted from the paper when the recorder is opened. The pivot of the lever of the direction pen is at the rear of the recorder carriage. The direction pen is moved by a cam follower, actuated by a half-heart-shaped cam below upper surface of recorder case.*

Recording of wind directions is somewhat more difficult. Leeds and Northrup Company are incorporating a simple arrangement in their new sulfur dioxide recorders. (Figure 1.) This is a modification of the old Friez eight-point direction recorder. It has 4 contacts actuated by an assembly of 4-135° cams on the shaft of the wind vane. These cams overlap so that in 4 alternate half-quadrants, single contacts are made and in the intervening half-quadrants double contacts are made. Four pens draw straight lines on the strip chart. The contacts on the vane cause one or two of the pens at a time to be drawn to a new position, indicating wind direction to 45°. Unlike the Friez recorder, which actuated the recording magnets for only one second out of each minute, the Leeds and Northrup magnets are actuated by the 1/60th mile contact on the anemometer. A direction that is being recorded steadily shows a wide line, that may be solidly inked. With less steady prevalence in that direction, the wide line will appear more open, and other directions will also be indicated. From the back and forth movement of the vane it is often possible to approximate the direction to about 23°.

The American Smelting and Refining Company has installed wind direction and velocity recording in a number of strip-chart $SO_2$ recorders. In the earlier installations the vane was mounted directly above the recorder and connected with the recording mechanism by a light shaft. In one case the vane turned a symmetrical heart-shaped cam against which a pen-carrying lever was operated so that the pen made a complete excursion through its arc on the paper in 180° of vane movement. The location of the pen lever on one side of the cam or the other was indicated by another pen, the position of which was changed when the heart-shaped cam turned from one 180° sector to the other. Thus the direction pen might record either the east and south or the west and north sectors in the same position on the chart and the sector pen would indicate which sector was being recorded. This simple device is useful in an area where the wind travel is principally in one direction and the opposite direction. In this case the least frequently occurring directions may be used as the positions for changing from one 180° sector to the other. It may be noted that when the wind is swinging back and forth across the position of sector change, the sector indicating pen may move so frequently that it is difficult or impossible to define the direction exactly. For this reason the sector changes should be made in the least probable wind directions.

A more complicated but more satisfactory system of recording direction is obtained by attaching to the vane shaft a 1 to 3 ratio, gear train mounted in a housing on top of the recorder (Figure 2). The driven shaft then moves 180° for each 540° of vane movement. A half heart-shaped cam in the recorder moves a pen-carrying lever through an arc on the paper corresponding to 540° of movement of the wind vane. By properly pivoting the lever this arc becomes practically a straight line on the paper. Provision must be made for re-positioning the half heart-shaped cam when it has been moved to either end of its 180° travel. This is accomplished by locating a microswitch so that a contact will be made when it reaches either end. The impulse from the microswitch allows a solenoid-operated lever and a special cam to turn the heart-shaped cam to its center position. The vane then causes the pen to assume a position on the paper 360° from the direction of

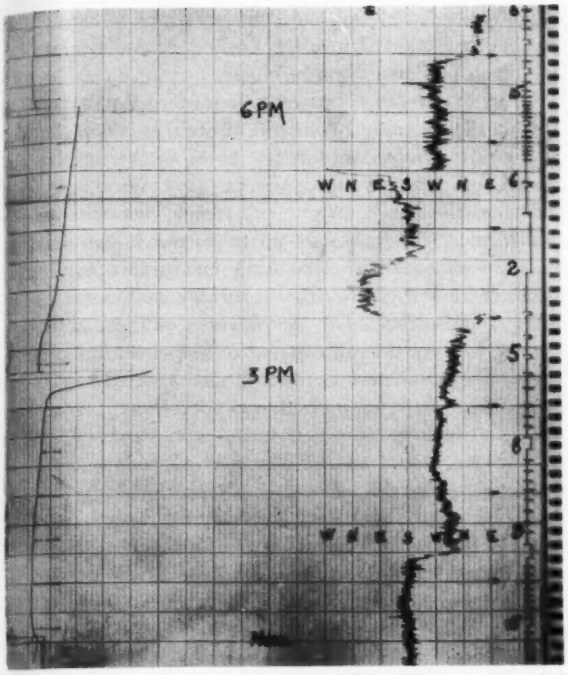


*Fig. 3.—Typical section of recorder chart, showing $SO_2$ trace, left; wind direction, center; and wind velocity, right.*

extreme travel and an unambiguous record (Figure 3) is obtained.

Both of the two foregoing methods of recording wind direction have been carried out using Selsyn motors instead of the mechanical connection between the vane and the recorder (Figure 4). Some electrical problems of stability had to be solved with the Selsyn motors but excellent operation has been obtained.

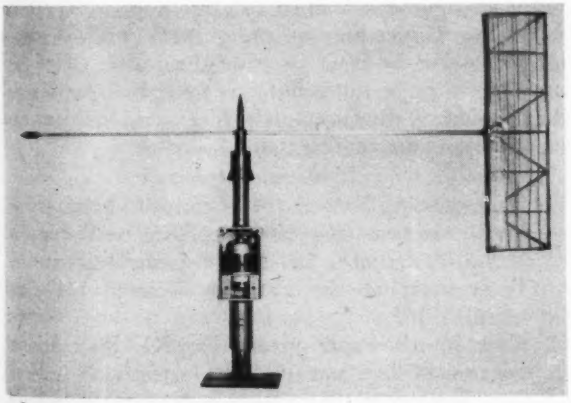

*Fig. 4.—Horizontal vane with Selsyn motor transmitter.*

In addition to direction and velocity it is desirable to record turbulence. This can be done by adding up the to-and-fro movements of a horizontal vane (Figure 4) or both the to-and-fro and up-and-down movements of a bivane (Figure 5). For this purpose a light gear train is used, (Figure 6) driven by the vane in one direction, using a gentle friction clutch, but blocked from moving in the other direction by springs that engage the gear teeth. Contacts are made with each 1,000° or submultiple of motion in one direction. The number of changes in direction of the vane can also be recorded if desired. All turbulence data are recorded as "pips" on the strip chart.

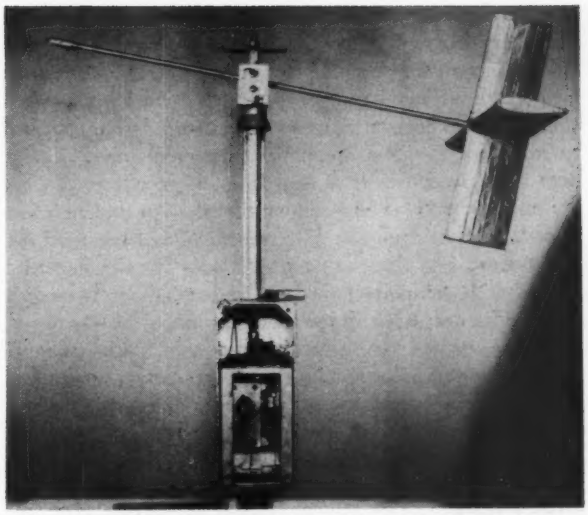

*Fig. 5.—Light bivane with stepping relay impulse transmitter for direction, velocity, and turbulence.*

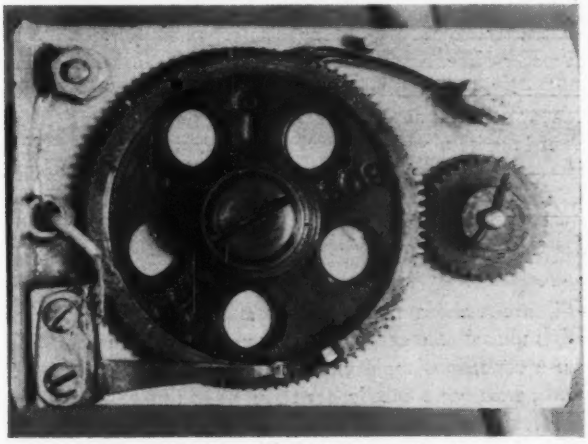

*Fig. 6.—Gear train (48 pitch gears) for recording horizontal and vertical oscillations of the wind vane as an index of turbulence.*

Light vanes are more responsive to changes of wind direction than heavy vanes, and, therefore, give more reliable turbulence values. They can be made of balsa wood covered with glass cloth and provided with shafts of duraluminum tubing. Counterpoised they weigh about one-half pound. Properly mounted they have operated for several years without trouble.

Another promising method of transmitting and recording direction, velocity, and turbulence data, which is particularly applicable to long-distance transmission, employs impulses sent through a pair of stepping relays. The sending and receiving stations are connected by 3 conductors or by 2 conductors and a ground. Radio transmission could also be employed. Direction is recorded by

two pens, one of which indicates one of the four quadrants and the other, ten degree intervals in the quadrant. Using 20 contacts on the stepping relays and operating at about 3 r.p.m. provision may be made to transmit wind direction, velocity, horizontal and vertical turbulence, and also to maintain the two stepping relays synchronized. For high wind velocities it is desirable to record velocity in ten-mile as well as one-mile intervals. An independent recorder rather than the $SO_2$ recorder has been used for this system, but there is no reason why the $SO_2$ recorder could not be employed. It is most convenient to record by tapping dots on a typewriter ribbon.

*Discussion*

Dispersion of pollutants in the air is largely a function of the atmospheric structure. The pattern of the wind direction record is determined by this structure and may be used to indicate good and poor dispersion conditions. The Brookhaven Meteorologists recognize four general patterns. (Figure 7).

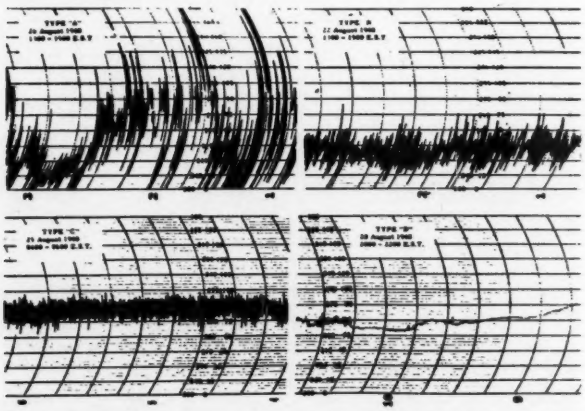

*Figure 7. Gustiness types—representative wind direction records at Brookhaven National Laboratory—August, 1948; data are for 355 ft. above ground.*

Chart A shows extreme vertical and horizontal thermally induced convective turbulence associated with strong lapse conditions on a clear day between 9 A.M. and 3 P.M., with wind speeds less than 10-18 m.p.h. Dispersion of smoke is excellent, but the smoke stream may loop excessively and momentary puffs of concentrated smoke may be brought to the ground from nearby stacks.

Chart B represents both mechanical and thermal turbulence due to strong wind, more than 10 m.p.h. with mild lapse, in the daytime, or with marked instability at night. The degree of turbulence increases with increase of wind velocity, and, therefore, the greater the velocity the more thermal turbulence will be replaced by mechanical turbulence. Conversely the greater the lapse the higher the velocity at which thermal turbulence changes to mechanical turbulence. Dispersion is usually very effective with this type of turbulence.

Chart C illustrates mechanical turbulence which occurs at night and on overcast days when the atmosphere is nearly neutral, but moderate to high winds prevail. The smoke stream tends to "cone" and at wind speeds of 5-15 m.p.h. considerable ground concentrations of smoke may be expected, according to the Bosanquet and Pearson (1) or Sutton (4) dispersion formulae.

Chart D represents inversion conditions usually at night and in the morning before the diurnal inversion breaks. At times the inversion does not break in the daytime but persists all day or even for several days. Wind velocity is less than 6-8 m.p.h. in our experience, but according to Smith et al (3), velocities up to 30 m.p.h. can occur at stack height without indicating measurable turbulence. Often there is slight horizontal turbulence but little or no vertical turbulence. The significances of these conditions depend to a considerable extent on the elevation at which the smoke is emitted. If released near ground level, it remains there, building up high concentrations. Ten or more years ago, before domestic heating was changed from soft coal to gas, Salt Lake City was blanketed nearly every morning during the winter, in a dense low-lying layer of smoke through which visibility usually ranged from 300 to 600 feet. The upper parts of the business buildings projected into clear air above the blanket. Later in the morning the smoke dispersed upward. On the other hand, hot smoke from a tall stack may rise 500 to 2,000 feet or more above the ground and travel away in a ribbon-like stream that may never touch the ground until the inversion breaks the next day. Katz (2) has described such a stream in Canada, which was followed for 60 miles. Smoke streams from tall stacks have been observed travelling nearly horizontally for many miles at an elevation 500-1,000 feet above the smoke blanket that covered part of Salt Lake Valley. Of course favorable dispersion from tall stacks under inversion conditions would depend on the presence of moderate winds aloft. Otherwise local accumulation would occur which might subsequently be brought to the ground. Accumulation on a still larger scale occurs in the Los Angeles Basin when low wind velocities and a layer of warm air which overlies the valley, effectively prevent escape of the pollutants, sometimes for several days. Evidently dispersion under inversion conditions can be poor or good according to local conditions.

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# A Continuous Recording Visibility Meter for Air Pollution Studies

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## I *Introduction*

Although the exact contribution of air pollution to decreased visual range is difficult to assess, reduced visibility is a complaint frequently encountered with many types of polluted atmospheres. Los Angeles smog is a striking example of a type of air pollution in which decreased visibility almost invariably accompanies other objectionable features, such as damage to sensitive plants and irritation of the eyes, nose, and throat. The potential value of continuous records of visibility to any systematic study of such pollution problems is thus obvious.

By international agreement, meteorologists define the "daylight visual range" as the distance at which a large dark object against the horizon sky is just recognizable. Since atmospheric pollution and illumination are seldom uniform all the way to the horizon in all directions from the observer, the meteorological range is frequently an average of the various visual ranges observed in different directions.

For the present application, it appeared advisable to define a "local" visual range as that range which would exist if the atmosphere and illumination in the immediate vicinity of the observer extended uniformly to the horizon in all directions. The instrument described in this paper was designed to record this "local" visual range directly and continuously throughout the hours of daylight.

The meteorological definition of "daylight visual range" implies that there is a minimum fractional contrast in brightness which the human eye is able to perceive. Blackwell (1) has shown that for natural or white light this liminal contrast ratio is dependent both on the absolute level of illumination and on the angle subtended at the eye of the observer by the object being observed. At subtended angles greater than a few degrees, however, the importance of the angular size of the object diminishes. The standard practice (2, 3, 4, 5) of assuming a constant liminal contrast ratio of two percent for instrumental measurements of visibility has been adopted in the definition of "local" range used with the present instrument.

Such an "instrumental visibility" is dependent only on the properties of the atmospheric aerosol (if the spectral distribution of the illumination does not vary), since factors affecting the discriminating ability of the human eye are eliminated. Consequently, the measured "local" visual range may at times deviate considerably from the observed meteorological range. Of the two, however, the defined instrumental quantity is rather more ideally suited to studies pertaining to the atmospheric aerosol in the immediate vicinity of the point of measurement.

## II. *Methods for Measurement of Apparent Contrast*

Steffens and Rubin (5), and Coleman and Rosenberger (6) describe photographic methods for measuring the apparent contrast ratio for black targets against the horizon sky. Coleman, et al (7) also describe a photoelectric photometer composed of a telescope containing a multiplier phototube at the focal plane. The telescope is aimed alternately at a black target and at the adjacent horizon sky, and the apparent contrast ratio is obtained from the relative photoelectric response. It has been shown (7, 8) that contrast data obtained from visual, photographic, and photoelectric measurements are in close agreement, provided that proper experimental precautions are taken.

Chaney (9) describes a recording visibility meter utilizing two black targets at different distances from a photoelectric photometer similar to Coleman's. A slow-speed, motor-driven diaphragm permits the two targets to be viewed in turn through different apertures. The photoelectric response for each diaphragm position is amplified and recorded on a strip-chart recorder. The visual range may be calculated from the chart readings.

Although the horizon sky may advantageously be substituted for one of the black targets (in effect placing that target an infinite distance from the instrument), it is claimed that an "artificial horizon" close to the instrument is a still more desirable substitute for continuous records, since the horizon sky is sometimes obscured and the incident illumination and atmospheric haze are seldom uniform from instrument to horizon. Such an "artificial horizon" should, of course, produce a photoelectric response proportional to that which the horizon sky would produce under conditions of uniform haze and illumination. Chaney (9) suggests an "artificial horizon" consisting of a liquid or solid suspension illuminated in the same manner as the optical path to the black target. This suspension should have optical properties like those of the atmospheric aerosol, and should be of sufficient depth to produce total obscuration of objects viewed through it.

(1) Blackwell, H. R., J. Opt. Soc. Am., **36**, 624 (1946)
(2) Lohle, F., Zeits. F. Angew. Met., **53**, 71-82 (1936)
(3) Wright, H. L., Q. J. Roy. Met. Soc., **65**, 411-442 (1939)
(4) Duntley, S. Q., J. Opt. Soc. Am. **38**, 237 (1948)
(5) Steffens, C. & Rubin, S., Proc. of 1st Natl. Air Poll. Symp. 193-208 (1949)
(6) Coleman, H. S. & Rosenberger, H. E., J. Opt. Soc. Am., **39**, 990 (1949)
(7) Coleman, Morris, Rosenberger, & Walker, J. Opt. Soc. Am., **39**, 515 (1949)
(8) Coleman, H. S., & Rosenberger, H. E., J. Opt. Soc. Am., **40**, 371 (1950)
(9) Chaney, A. L., Proc. of U. S. Tech. Conf. on Air Poll. (McGraw-Hill), 679 (1952)

Chaney (9) also discusses the need for applying corrections to the recorded photoelectric responses, to allow for incomplete blackness of the "black" target and for light scattered internally in the photometer.

## III *Description of Instrument*

The instrument described here consists essentially of a photoelectric photometer aimed at a dark target, a photovoltaic cell exposed to an "artificial horizon", and a modified Leeds and Northrup "Micromax." It is shown schematically in Figure 1.

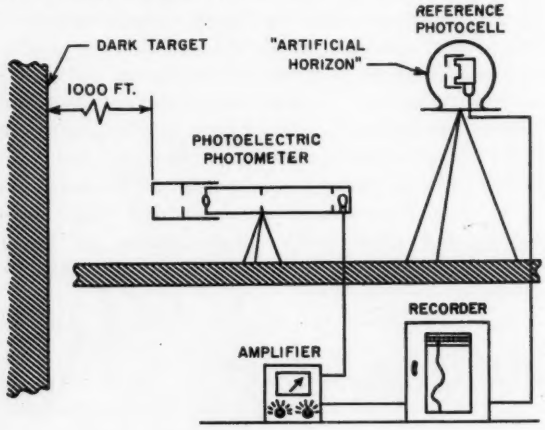


FIG. 1

SCHEMATIC DIAGRAM OF RECORDING VISIBILITY METER

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The components of the photometer include a 36-inch focal length telescope, equipped with a baffled black sunshade and internal black baffles. A phototube is mounted at the focal plane of the telescope and is connected to a high-gain amplifier. Both the phototube and the amplifier are components of a "Densichron" photoelectric densitometer, which produces a linear photoelectric output free from amplifier drift. The sensitivity is not as high as may be obtained with a photomultiplier tube, and consequently the dark target upon which the photometer is focussed must be at a relatively long distance, (and therefore large) for adequate precision in the desired range of visibilities.

In practice, the dark target is a black gas holder located 1000 feet away in a nearly southerly direction so that its face is not illuminated by direct sunlight.

The long baffled black sunshade over the lens, and the black baffles within the photometer minimize the amount of "flare light" scattered to the phototube by the lens and inner walls of the photometer.

The photovoltaic cell is a Weston "Photronic" equipped with an iris diaphragm for adjustment of sensitivity. A white translucent globe mounted over it serves as an "artificial horizon."

The output from the photovoltaic cell and the amplified output from the photometer are combined in a balanced bridge circuit in the "Micromax" recorder, in such a manner that the position of the slide-wire corresponding to null galvanometer current is determined by the ratio of these outputs. A high-sensitivity DC galvanometer is employed in the "Micromax" circuit.

The ratio of photoelectric responses determines the "local" visual range for the ideal condition where the atmospheric aerosol and the incident illumination are uniform between the instrument and the dark target, provided that proper allowances are made for light reflected from the dark target, and for residual photometer "flare light." Consequently the recorder chart may be graduated in units of visual range, making the instrument direct-reading, with the attendant increased utility for routine continuous measurements.

## IV *Optical Theory*

Figure 3 is a mathematical representation of the optical situation depicted in Figure 1. In Figure 3, J represents the intensity of the total incident light flux falling upon the increment of the light path from the target to the photometer. In practice, of course, J is a composite of a multitude of fluxes, all having different intensities, directions, and wavelengths. In this simplified treatment, however, J is taken to represent a single light flux equivalent to the sum of its components in its effects.

Similarly, I is taken to represent the intensity of a single light flux equivalent in effect to the sum of the fluxes from the direction of the target. The intensity I will be changed by an amount dI in passing through the distance dX. It will be decreased by some fraction due to scattering and absorption, and it will be increased by some fraction of the incident light flux, J, which is scattered in the direction of I. This may be expressed by the differential equation

$$\frac{dI}{dX} = -\gamma I + \sigma J, \qquad (1)$$

in which $\gamma$ is a "composite" coefficient of attenuation at point, X, and $\sigma$ is a "composite" scattering coefficient at point X.

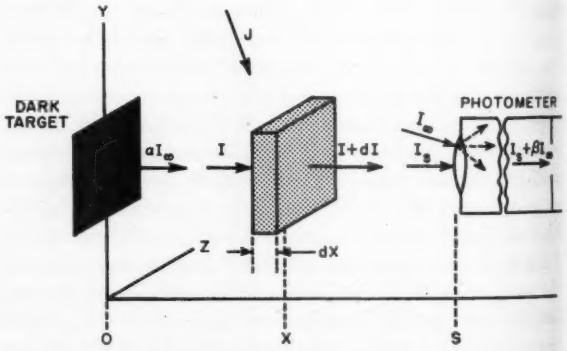


*Figure 2. Optical relationships.*

If the atmospheric aerosol and the incident illumination are uniform for the entire distance between target and photometer, then $\gamma$, $\sigma$, and J are constant at any instant for all values of X, and the integral of equation (1) reduces to

$$I = ce^{-\gamma X} + \left(\frac{\sigma}{\gamma}\right) J \qquad (2)$$

in which c is an integration constant.

Denoting I by $I_v$ at X = V, the visual range,

$$I_v = ce^{-\gamma V} + \left(\frac{\sigma}{\gamma}\right) J \qquad (3)$$

The three instantaneous constants, $\sigma$, $\gamma$, and c, in equation (3) may be fixed by substituting three independent sets of values of I and X in equation (2).

With X equal to S, the known distance from target to photometer, let the intensity of the light flux from the direction of the target be denoted by $I_s$. Then by equation (2)

$$I_s = ce^{-\gamma S} + \left(\frac{\sigma}{\gamma}\right) J \qquad (4)$$

At $X = \frac{1}{\infty}$, the target is completely obscured by the intervening aerosol, and the intensity of the light flux from the direction of the target is the same as that from the adjacent horizon sky. Denoting this light flux by $I_\infty$ in equation (2),

$$I_\infty = \left(\frac{\sigma}{\gamma}\right) J \qquad (5)$$

The "artificial horizon" in Figure 1 effectively places the equivalent of an infinite amount of atmospheric aerosol in front of the photovoltaic cell. As a result, the intensity of the light flux reaching the photovoltaic cell will be approximately proportional to $I_{\frac{1}{\infty}}$ when the cell is pointed in a direction parallel to the photometer, provided that the "artificial horizon" is illuminated in the same manner as the optical path between dark target and photometer, and that the ratio $\sigma/\gamma$ in equation (5) remains approximately constant as the visibility varies and as the sun moves from east to west.

With the photovoltaic cell pointed south, the condition regarding illumination is very nearly satisfied in practice, except for minor differences due to light reflected from surrounding objects. Constancy of the coefficients $\sigma$ and $\gamma$ was stipulated only with respect to X, and not V. Obviously, both $\sigma$ and $\gamma$ are dependent on the composition and size distribution of the aerosol and, in addition, $\sigma$ is dependent on the angle between J and I. Although the translucent glass might exhibit a variation with scattering angle for its $\sigma$ proportional to that for $\sigma$ of the aerosol, this type of compensation is not necessary. The north-south orientation of both optical paths insures approximate constancy, throughout the day, of the scattering angle for the bulk of the incident light (direct sunlight). Consequently, significant variations of the scattering and attenuation coefficients are effectively restricted to those due to corresponding variations in the properties of the aerosol.

The attenuation coefficient is the sum of the true absorption coefficient and the total scattering coefficient. For relatively non-absorbing aerosols (white or colorless particles) then, the ratio $\sigma/\gamma$ approaches the ratio of two scattering coefficients. As long as variations in the size distribution and refractive index of the aerosol particles remain relatively small, approximate constancy of $\sigma/\gamma$ is maintained. Under these conditions the "artificial horizon" will perform its function satisfactorily.

The above considerations emphasize the importance of the north-south orientation, and also show that this type of "artificial horizon" is distinctly unsuited for applications where the aerosol is colored or dark, since in these cases $\sigma/\gamma$ will rapidly decrease as the visibility decreases, due to the preponderant influence of the absorption component of the attenuation coefficient.

For the third independent value of I in equation (2), X may be set equal to zero, in which case the light flux from the direction of the target is that due solely to reflection from the target surface. Since the target is purposely situated so that it is not illuminated by direct sunlight, the light falling on it will be principally sky-light plus reflected light from the ground and nearby objects. If the diffuse reflectivity of the target is very low, it will be sufficiently precise for the north-south orientation employed, to assume that the intensity of the light falling on the target is proportional to $I_\infty$, and consequently that the intensity of the light flux reflected from it in the direction of the photometer is also proportional to $I_{\frac{1}{\infty}}$. Substitution of this relationship in equation (2) for X = O gives

$$\alpha I_\infty = c + \left(\frac{\sigma}{\gamma}\right) J, \qquad (6)$$

where $\alpha$ is the proportionality constant, and may be considered a sort of "effective diffuse reflectivity" of the target.

Simultaneous solution of equations (4), (5), and (6) for $\sigma$, $\gamma$, and c, and subsequent substitution in equation (3), makes possible the solution for V:

$$V = \frac{(S)\ln\left(\frac{1-\alpha}{1-I_v/I_\infty}\right)}{\ln\left(\frac{1-\alpha}{1-I_s/I_\infty}\right)} \qquad (7)$$

in which the quantity $(1-I_v/I_\infty)$ is the liminal contrast perceptible to the eye, and is taken to be a defined constant. Denoting the liminal contrast by E,

$$V = \frac{(S)\ln\left(\frac{1-\alpha}{E}\right)}{\ln\left(\frac{1-\alpha}{1-I_s/I_\infty}\right)} \qquad (8)$$

In spite of the sunshade over the lens of the photometer, some light from the horizon sky adjacent to the target will reach the lens and be scattered toward the phototube by the lens and inner walls. The effect of this "flare light" is to reinforce the intensity of the light flux $I_s$ by some small fraction of the light flux $I_\infty$. Thus, if $I_s'$ is the intensity of the light flux actually reaching the phototube,

$$I_s' = I_s + \beta (I_\infty). \qquad (9)$$

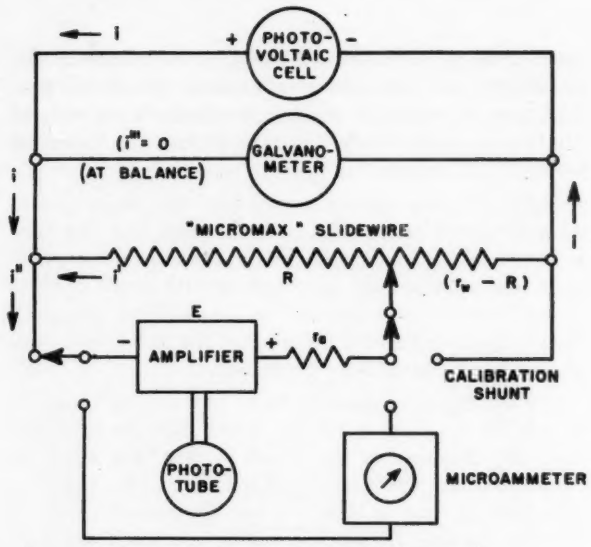


*Figure 3—Measuring circuit for visibility recorder.*

In equation (9), $\beta$ is the photometer "flare light" coefficient for a target of a given angular size against the horizon sky.

Expressing equation (8) in terms of $I'_a$ (and $I'_\infty$, for $S = \infty$),

$$V = \frac{(S)\ln\left(\frac{1-\alpha}{E}\right)}{\ln\left[\frac{(1-\alpha)/(1+\beta)}{(1-I'_a/I'_\infty)}\right]} \qquad (10)$$

It is worth noting that the visual range is independent of the intensity of the incident light flux, J, and that the only remaining variable is the ratio of intensities at the phototube, $I'_a/I'_\infty$.

## V *Measuring Circuit*

The choice of electrical circuit used with the "Micromax" recorder was governed by the characteristics of the recorder itself, and of the phototube (and amplifier) and photovoltaic cell used to detect the light intensities.

A Leeds and Northrup "Micromax" equipped with a high-sensitivity DC galvanometer was utilized as the recording device. The total resistance of the recorder slide-wire was measured to be 164 ohms, of which the sliding contact taps off from 1 to 119 ohms as the recorder pen moves from 0 to 100 chart divisions.

The "Densichron" phototube and amplifier produce a DC output with an open-circuit EMF proportional to the light intensity, at a given amplifier setting. Measurement of the variation of the output current with varying external resistance established that the effective internal resistance of the amplifier output circuit is 2600 ohms.

The characteristics of the Weston "Photronic" photovoltaic cell are quite different from those of the phototube. With photovoltaic cells it is the short-circuit current which is proportional to the light intensity, since the internal resistance is not constant. For linear response it is therefore imperative that the photovoltaic cell be so connected in the recorder circuit that there is no potential across its terminals when the circuit is at balance. This condition may be satisfied by connecting the "Micromax" galvanometer directly across the cell terminals.

Reference to equation (10) shows that the entire range of visibilities from zero to infinity involves a change in the ratio $(I'_a/I'_\infty)$ from (1) to $(\alpha + \beta)\ /\ (1 + \beta)$, where $\alpha$ and $\beta$ may each be expected to be very slightly larger than zero. The measuring circuit shown in Figure 4 is capable of achieving balance over this entire range of visibilities or any portion thereof, by varying a resistance of not more than 118 ohms, while maintaining zero potential across the terminals of the photovoltaic cell.

## VI *Graduation of Recorder Chart*

The network equations for the circuit shown in Figure 4 are (at balance)

$$i + i' - i'' = 0 \qquad (11)$$

$$(R)i' + (r_w - R)i = 0 \qquad (12)$$

$$E - (r_a)i'' - (R)i' = 0 \qquad (13)$$

Elimination of i′ and i″ from these gives

$$\frac{E}{i} = \frac{(r_w)\ (r_a)}{R} + (r_w - R) \qquad (14)$$

E/i will be exactly proportional to $I'_a/I'_\infty$ under the ideal conditions stipulated in the discussion of optical theory. Assuming this proportionality to hold for the practical case also,

$$\frac{I'_a}{I'_\infty} = k\left[\frac{(r_w)\ (r_a)}{R} + (r_w - R)\right] \qquad (15)$$

in which the required value of k is obtained by adjusting the amplifier gain and selecting appropriate apertures for the phototube and photocell.

This value of k may be determined by assigning an arbitrary value to R for a case where $I'_a/I'_\infty$ is known. By equation (10), $I'_a/I'_\infty = (\alpha+\beta)/(1+\beta)$ at $V=\infty$.

Denoting the corresponding value of R by $R_\infty$,

$$k = \frac{(\alpha + \beta)/(1 + \beta)}{\left[\frac{(r_w)\ (r_a)}{R_\infty} + r_w - R_\infty\right]} \qquad (16)$$

Equations (10), (15), and (16) may be combined to express V in terms of the variable R, the defined constant E, the experimental constants $\alpha$, $\beta$, $r_w$, and $r_a$, and the arbitrary constants S and $R_\infty$:

$$V = \frac{(S)\ln\left(\frac{1-\alpha}{E}\right)}{\ln\left\{\left(\frac{1-\alpha}{\alpha+\beta}\right)\left[\frac{(r_w)\ (r_a)}{R'_\infty} + r_w - R_\infty\right] \Big/ \left(\frac{1+\beta}{\alpha+\beta}\right)\left[\frac{(r_w)\ (r_a)}{R_\infty} + r_w - R_\infty\right] - \left[\frac{(r_w)(r_a)}{R} + r_w - R\right]\right\}} \qquad (17)$$

Measurement of the constants $r_w$ and $r_a$ was described in the discussion of the measuring circuit.

Evaluation of $\beta$ may be made by utilizing equation (9) twice: once for the case where $I_a = I_\infty$ and once for the case where $I_a = I_o = aI_\infty$. Denoting the corresponding values of $I'_a$ respectively by $I'_\infty$ and $I'_o$, and dividing the second equation by the first,

$$\frac{I'_o}{I'_\infty} = \left(\frac{\alpha + \beta}{1 + \beta}\right) \qquad (18)$$

With the aid of a microammeter on the amplifier output (see Figure 4) the relative photoelectric response equal to $I'_o/I'_\infty$ may be measured by pointing the photometer successively at an auxiliary target at close range, and at the adjacent horizon sky. If the auxiliary target is constructed to be essentially perfectly black, and to appear the same angular size to the photometer as does the main target, dependence of equation (18) on $\alpha$ is removed ($\alpha = o$) without affecting $\beta$. A hollow cylindrical tube open at one end and lined with black velvet on the inside makes a very nearly perfectly black target, if its length is several times its diameter.

Exact determination of the value of $\alpha$ is much more difficult. Perhaps the only really satisfactory method is to determine the ratio $I'_a/I'_\infty$ at a time when the visibility is known to be at least equal to the highest value it is desired to record. This ratio may be measured in a manner analagous to that used for evaluating $\beta$, but using the main target and the adjacent horizon sky. The value of $\alpha$ may then be obtained by trial from equation (10) with reasonable accuracy since V is very large. Considering the fact that $\alpha$ is assumed to be exactly constant only for simplicity, the above method of evaluation is certainly all that is justified.

Experimental values of $\alpha$ and $\beta$ determined as described above were 0.010 and 0.017 respectively.

The choice of the arbitrary constants S and $R_\infty$ is governed by three considerations:

1. The range of V it is desired to record must lie within the limits of the recorder chart.
2. The above range of V should utilize as much as possible of the total chart width, for maximum precision in making readings.
3. The signal strength from the amplifier must be adequate to activate the "Micromax" galvanometer at the highest visibility it is desired to record.

With the phototube and amplifier employed, a target distance, S, of approximately 1000 feet was required for satisfactory signal strength at visibilities of the order of 60 miles. Conveniently, for this value of S and the determined values of $\alpha$ and $\beta$, the choice of $R_\infty = r_w$ resulted in the range of visibilities from 0 to 60 miles utilizing nearly the entire chart width.

Utilization of the entire length of the "Micromax" slidewire for $R_\infty$ is convenient because it provides an easy, reproducible method for finding the proper amplifier setting. By switching in the calibration shunt shown in Figure 4, when the photometer is pointed at the horizon sky adjacent to the target, the amplifier gain may be adjusted to give null galvanometer deflection corresponding to $I'_a = I'_\infty$. Since the calibration shunt is intended to represent balance for $V = \infty$, or $I'_a = I'_o$ the amplifier gain must then be increased by the known factor $I'_\infty/I'_o$, or $(1+\beta)/(a+\beta)$, as indicated by equation (18). This may be done with the aid of the microammeter shown in Figure 4. Subsequent focussing of the photometer on the target makes the instrument ready for operation with the calibration shunt again switched out of the circuit.

In order to graduate the chart directly in terms of integral values of V, it is desirable (though not essential) to have an explicit expression for the chart reading D, (in divisions from 0 to 100) in terms of V in miles. The chart reading is linear with respect to R in ohms (uniformly wound slidewire) according to the measured relation:

$$R = 1 + 1.18\,D \qquad (19)$$

Equations (17) and (19) may be combined after substitution of all defined, experimental, and arbitrary constants to give the desired solution for D. For precise numerical computation, this solution is best expressed in the form of the expansion

$$D = \frac{3.79}{\left[f(V) + \dfrac{4.69 \times 10^{-5}}{f(V) + \dfrac{4.69 \times 10^{-5}}{f(V) + \ldots .}}\right]} - 0.8 \qquad (20)$$

where

$$f(V) = 1.0255 - (0.477)^{1/V} \qquad (21)$$

A template such as one shown alongside the visibility record in Figure 5 may be graduated by means of equations (20) and (21).

VII *Performance of Instrument*

The visibility recorder has been in continuous operation in Pasadena, California, since February 1952 in connection with Stanford Research Institute's study of the air pollution problem in Los Angeles County. Its performance has been entirely satisfactory for its intended purpose. Its principal disadvantage is its dependence on natural illumination, which makes it non-operable at night. On the credit side, is its demonstrated ability to operate reliably for weeks at a time with little or no attention.

Agreement between the recorded visibilities and subjective estimates has been within the limits of confidence of the subjective estimates, except for momentary fluctuations such as those caused by scattered clouds or local emissions of smoke.

The close correlation between the recorded visibilities and the concentration of atmospheric oxidant capable of liberating iodine from neutral buffered potassium iodide solution is shown in Figures 4 and 5. This oxidant has been found to be principally ozone, and its concentration is closely related to the frequency of complaints of eye-irritation, plant damage, and "smogginess" in general.

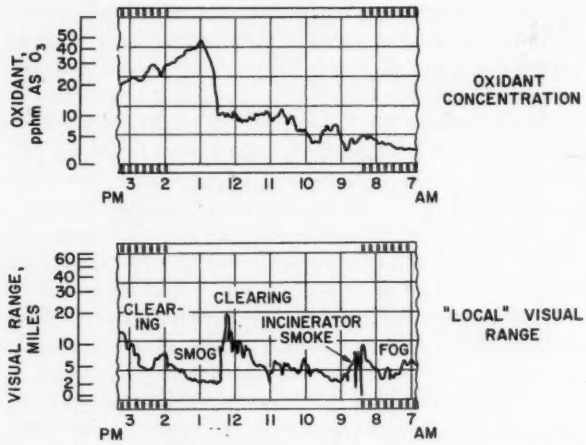


*Figure 4. Typical visibility and oxidant records, and illustration of changes in appearance of target.*

Obviously, the visual range is not in itself a criterion of the intensity of atmospheric pollution, nor even of particulate pollution, since natural fog and rain are not normally classed as pollutants. Nevertheless, visibility is a function (albeit a complicated one) of the particulate content of the air and, as such, finds a place in air pollution studies.

A complete quantitative discussion of the effects of non-ideal conditions on the recorded visibilities is beyond

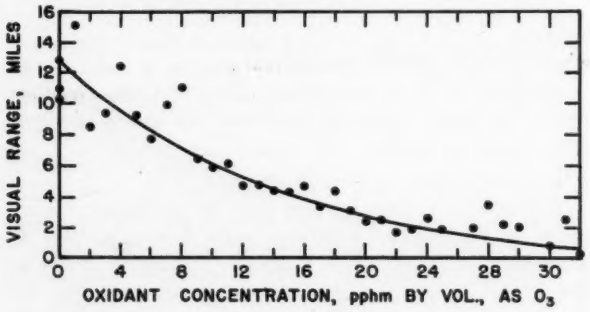


*Figure 5. Average visibilities at given oxidant concentrations.*

the scope of this paper. Some of the qualitative effects may be mentioned, however. As noted previously, scattered clouds cause widely fluctuating and erratic readings as they pass over the optical path and the "artificial horizon." Local emissions of smoke into the optical path similarly cause momentary deviations from the normal chart trace (see Figure 4).

Orchard smudge or dark dust can be expected to cause the recorded visibilities to be too high, since the value of $\sigma/\gamma$, for such atmospheres will be significantly lower than during calibration.

A uniform overcast can be expected to cause slightly low readings, since a higher proportion of the total incident light will fall on the face of the target, thereby increasing the effective magnitude of $\alpha$ above its assumed constant value.

Although the recorded visibilities are independent of the intensity of the incident light, variations in its spectral distribution could theoretically affect the readings. Not only is the ratio $\sigma / \gamma$ dependent on the spectral distribution, but the photoelectric responses of the phototube and photocell are functions of wavelength. It is well known that the incident light when the sun is rising or setting contains proportionately more red than during mid-day, especially if the atmosphere is hazy. Fortunately, the photoelectric response curves for the photocell and phototube used in this instrument are very nearly identical, thus making unnecessary the use of narrow-band optical filters, with attendant loss of sensitivity.

While the number of possible sources of error has been shown to be large, they have not been found to be serious enough in effect to detract from the usefulness of the instrument for its intended function.

VIII *Acknowledgments*

The authors are indebted to Dr. Sylvan Rubin for his personal help in the design of this instrument, and to Dr. Carsten Steffens for his criticisms during the preparation of this paper.

## BLUTH HEADS TEST PROGRAM

Marc G. Bluth, director of the NCA-ARCA Sales Engineering Council, will not move from Chicago, as announced in the May issue of *APCA News,* but will conduct his new operation from Room 1307, 104 W. Monroe Street, Chicago 3, Ill.

The project is a joint effort created and sponsored by the National Coal Association and the American Retail Coal Association, and is intended to promote the sale and use of commercial and small industrial steam plant bituminous coal moving through retail coal merchants' facilities. The program will be limited, for the time being, to certain counties in the states of Illinois, Indiana, and Michigan.

The sales engineering service is intended as a help to determine the fuel needs of Coal Association customers, and to assist them in deciding upon combustion and boiler room equipment and related accessories.

It is expected that a practical procedure will be developed out of this test project which can be adopted and extended to other states, and perhaps eventually to most of the bituminous coal consuming areas.

# Light Scattering Instruments as an Aid in Air Pollution Measurements

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## 1—INTRODUCTION

The measurement of aerosol (particulate) contaminants by light-scattering is greatly complicated by the wide variety of aerosols occurring in the atmosphere. Five variables influence all scattered light measurements: (1) concentration, (2) particle size, (3) particle shape, (4) refractive index and (5) absorption index* (which determines the transparency and color).

The most important quantity in air pollution is the concentration, expressed either as mass concentration ("dust load") or the particle number concentration. The quantity second in importance is the particle size which largely determines both the rate of settling and the "visibility" (more precisely, the visual range*) of an aerosol of given mass concentration. Particle shape (1, 2) usually has a relatively minor influence on the settling rate. The refractive index usually lies between 1.33 (water) and 2.0 (many minerals), and in this range has less influence on the visibility than does the particle size. The absorption index usually has a minor influence on the visibility except for nearly opaque particles such as carbon (refractive index=2.0, absorption index=0.33). (3)

Light-scattering measurements alone cannot distinguish quantitatively between concentration and particle size (even at given values of the other three variables) when a range of particle size occurs. The range of particle size occurring in atmospheric contaminants may be as much as 100 fold, from 0.1 micron diameter or less to about 10 microns (18 cm/min. settling velocity). However, light-scattering measurements can give useful qualitative information on air pollution, particularly if supplemented by collection methods such as dust-fall or filtration. They also have the advantage of providing continuous measurements which can be readily observed and recorded.

The present paper describes a portable instrument for the continuous recording of air pollution by measurement of forward light-scattering. The measurements give approximately the variation in visibility, or its converse the turbidity which is a measure of the mass concentration provided the particle size and type remain relatively constant.

The choice of this type of measurement is based on the Mie theory of light-scattering by isotropic spheres. According to this theory the total light scattered and the angular distribution of its intensity are determined by the ratio of the sphere radius, r, to the wavelength, $\lambda$, and the ratio of the refractive index, m, of the sphere to that of the suspending medium (unity for air). The total light scattered is usually greater than that intercepted by the geometrical cross-sectional area of the sphere (except for spheres below 0.3 micron diameter). The scattering area coefficient, $K=S/\pi r^2$, is defined as the ratio of the scattering cross-section, S, to the geometric cross-section of transparent spheres. The extinction area coefficient, $K_e$, is similarly defined and gives the total light scattered and absorbed by absorbing spheres.

As described in detail in many references: (4-7)

$$K = \frac{2}{a^2} \sum_{n=1}^{\infty} \frac{|a_n|^2+|p_n|^2}{2n+1} \qquad (1a)$$

or

$$K = \frac{1}{a^2} \int_0^{\pi} (i_1 + i_2) \sin \gamma \, d\gamma \qquad (1b)$$

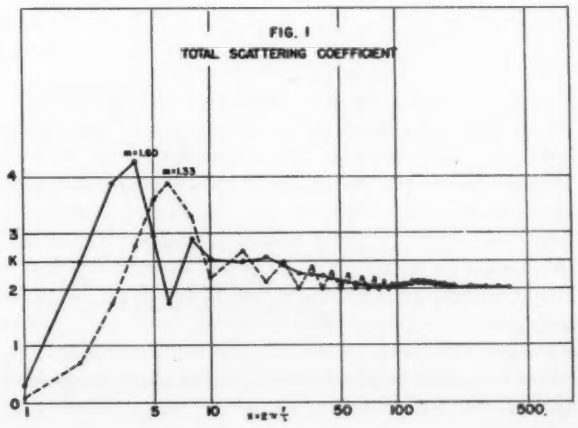
and

$$K_e = \mathrm{Re} \frac{2}{a^2} \sum_{n=1}^{\infty} j\,2n + 1\,(p_n - a_n) \qquad (2)$$

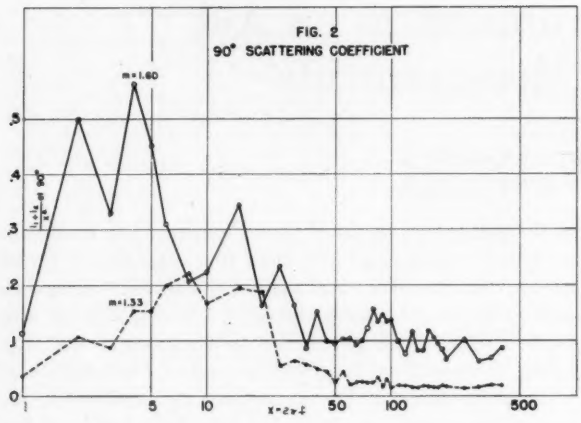
where $j = \sqrt{-1}$ and Re means real part of.

The quantity $a = 2\pi r/\lambda$, where r is the particle radius and $\lambda$ is the wave length of the incident light. The angle $\gamma$ is the angle between the scattered light and the backward direction of the incident light. It is usually more convenient to use the angle $\theta = 180°-\gamma$, the angle between the forward direction of the incident light and the scattered light.

The quantities $a_n$ and $p_n$ are complex functions of $a$ and the refractive index, m. The refractive index is real for transparent spheres or complex for absorbing spheres.




*Defined below.




In the latter case, the complex refractive index, $m_c = m(1 - jk)$, where $j = \sqrt{-1}$, and k is the absorption index, related to the usual absorption coefficient, a, by the equation, $a = 4\pi mk/\lambda$. For either type of material, Equation 1 gives the light scattered by the sphere and Equation 2 gives the sum of the scattered plus absorbed light.

The quantities $i_1$ and $i_2$ are proportional to the intensities of the two polarized components scattered at a given angle when the particle is illuminated by unpolarized light. They are complicated functions of $a$, m and $y$.* The intensity per unit solid angle is $(i_1 + i_2)\,\lambda^2/8\pi^2$.

The total scattering and the intensity distribution have been calculated for a wide range of particle sizes, usually for transparent spheres of real refractive index. Figure 1 shows the results obtained (6) for real refractive indices 1.33 and 1.60. The abscissas are the values of $a=\pi d/\lambda$. (When the wavelength is 0.524 microns, the diameter of the sphere, $d + a/6$ microns.) The ordinates are the scattering area coefficient, K. Figure 2 shows the intensity functions, $i_1+i_2$, at 90° to the incident beam. The abscissas are the values of $a$. The ordinates are $(i_1+i_2)/a^2$, which, according to Equation 1 b, gives the "90° scattering coefficient." Figures 1 and 2 show that the total scattering varies comparatively regularly with particle size, while the scattering at 90° oscillates more violently. For all refractive indices it is found that the total scattering coefficient, K is nearly 2 for values of $a$ greater than about 60. (8)

Approximately similar relationships hold for the extinction coefficient, $K_e$, although relatively few detailed calculations have been made for absorbing particles. Some results are given in Reference 7, Figures 5-7. Exact calculations have not been made for particles of non-spherical shape, but the above results may be expected to show the order of magnitude of their scattering.

## 2—Methods of Measurement of Air Pollution By Light-Scattering

Three methods of measurement of aerosol concentration are commonly used: (4) (1) transmission, (2) scattering at a right angle to the incident beam, and (3) forward scattering, i.e., near the emergent illuminating beam.

The transmission method provides an absolute measure of the turbidity, t, i.e., the scattering cross-section per unit volume of aerosol, provided certain precautions are taken. If $I_o$ is the intensity (flux per unit area) of the incident parallel beam of wavelength, $\lambda$, then the intensity, I, of the transmitted beam is:

$$I = I_o e^{-tl} \qquad (3)$$

where 1 is the path length in the aerosol. For n particles, all of the same size, per unit volume, the turbidity, $t = K\pi r^2 n$ or $K_e \pi r^2 n$, for transparent or absorbing particles, respectively.

As described above, for transparent or absorbing particles illuminated by visible light, K and $K_e$ vary from about 0.1 at 0.1 micron diameter to 4 at 1 micron diameter and then approach 2 at larger diameters. The particle concentration may be taken to vary from, $n = 10^9$ to $10^7$ particles per liter for the larger particles and up to $10^9$ for 0.1 micron haze particles. For reliable transmission measurements, $I/I_o = 1/2$, approximately. Consequently, the requisite path length becomes excessive as shown in Table I.

Table I

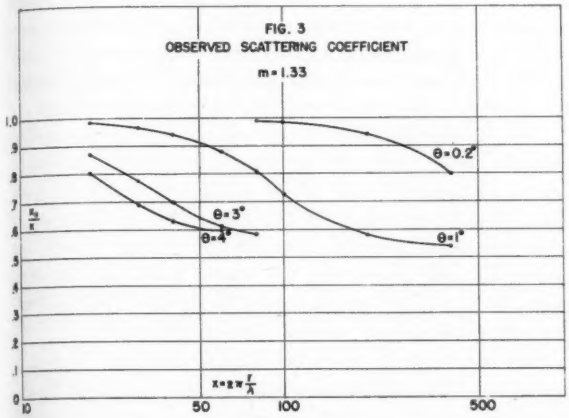
| Particle Diam. Microns | K | Path Length Meters | | Turbidity — per meter | | Visual Range* Meters | |
|---|---|---|---|---|---|---|---|
| | | $n=10^7/1$ | $n=10^3/1$ | $n=10^7/1$ | $n=10^3/1$ | $n=10^7/1$ | $n=10^3/1$ |
| 10 | 2 | 0.43 | $4.3\times10^3$ | 1.6 | $1.6\times10^{-4}$ | 2.5 | $2.5\times10^4$ |
| 1.0 | 4 | 22 | $2.2\times10^5$ | $3.1\times10^{-2}$ | $3.1\times10^{-6}$ | $1.3\times10^2$ | $1.3\times10^6$ |
| 0.3 | 0.5 | $2\times10^3$ | $2\times10^7$ | $3.5\times10^{-4}$ | $3.5\times10^{-8}$ | $1.1\times10^4$ | $1.1\times10^{10}$ |

*Defined by Middleton (9) as the distance at which a black object against a white background is just obscured, for which $I/I_o = 0.02$.

*For more detailed definitions of the above quantities, see references 4-7.

From Table I it is seen that the path length has a practical value only for the larger particles at the highest concentrations occurring in atmospheric aerosols. It is evident that a portable instrument could not be constructed on a transmission basis.

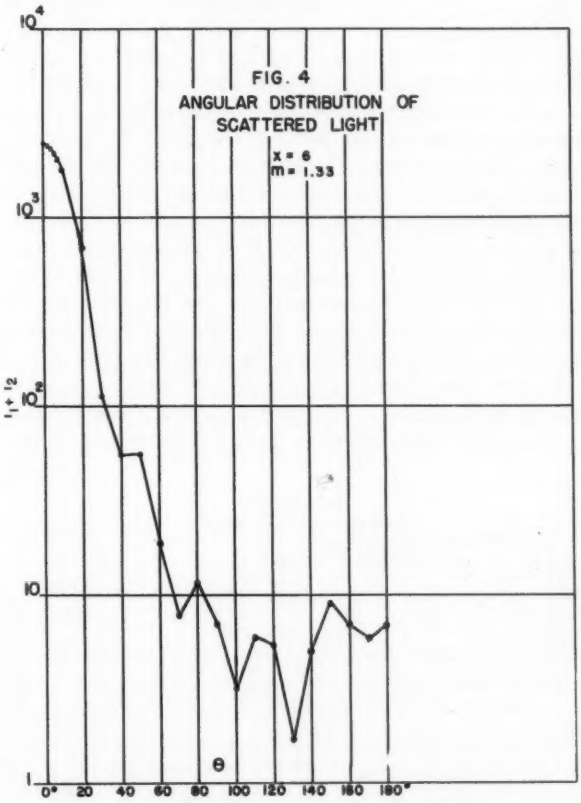
When practicable, transmission measurements are subject to an error which increases with increasing particle size. The Mie theory as well as numerous observations show that the angular dissymmetry of the scattered light increases rapidly with particle size. The light scattered at small angles, $\theta$, from the transmitted beam may be several orders of magnitude greater than that scattered at 90° or 45°. Unless the angular opening of the measuring device is very small, much of the forward scattered light will enter the collector along with the transmitted beam, resulting in a lowered value for the scattering coefficient and the turbidity.




Gumprecht and Sliepcevich [10] have calculated the observed scattering coefficient, $K_o$, for transparent spherical particles of refractive index 1.20-1.44 and various diameters, as a function of angular opening, 2 $\theta$, of the collector. Figure 3 shows some of their results for particles of refractive index, m = 1.33. The abscissas are the values of *a*. The ordinates are $R = K_o/K$, the ratio of the observed scattering coefficient to the true scattering coefficient. The observed value of the turbidity will be, $t = R K \pi r^2 n$. For example, when the collector subtends a half-angle, $\theta = 1°$, at the scattering particles, the turbidity will be reduced 10 per cent for 10 micron diameter particles.

The scattering at 90° is frequently used to obtain the turbidity or concentration. As Figure 2 shows, 90° scattering is more affected by changes in particle size and refractive index than is the total scattering. Furthermore, the intensity of light scattered at 90° is relatively very low for particles greater than 0.2 microns diameter. Because of the angular dissymmetry referred to above, most of the light is scattered into a small cone about the forward direction for all but the smallest particles in atmospheric aerosols.

On the other hand, the light scattered into a cone of half-angle, $\theta$ is almost equal to 30°, about the forward direction may be 100 to 10,000 times that scattered in all other directions. The angular distribution of scattered intensity for small particles from 0.1 to 1 micron diameter (at $\lambda = 0.524$ microns) is given in Reference 5 for several refractive indices. Gumprecht & Sliepcevich [11] have calculated the intensity distribution for particles of refractive index 1.33 and diameters from 1 to 7 microns. Figure 4 shows the intensity distribution for a water droplet (index 1.33) of 1 micron diameter. The abscissas are the angles, $\theta$, from the emergent illuminating beam, and the ordinates are the intensity components, $i_1+i_2$.

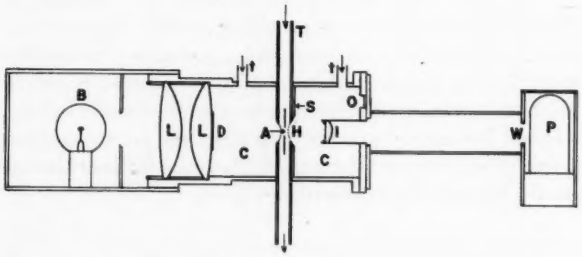



### 3—The Forward-Scattering Smoke Photometer

Figure 5 shows a diagram of the apparatus used to observe the light scattered at small angles to the forward direction of illumination. The drawing shows a cross-section through the axis of the cylindrical smoke illuminating chamber, C, (2-1/2 in. diameter and 4-1/2 in. long) and the 1P21 photomultiplier tube, P. Smoke is drawn in and out through the tube, T, by means of a small air pump, at a rate of about 10 1/min. The smoke is prevented from entering the chamber and dirtying the lens surfaces by simultaneously drawing a small flow of filtered air in through the side tubes, t, and out through holes, H, in the smoke tube. The smoke is illuminated by means of

FIG. 5

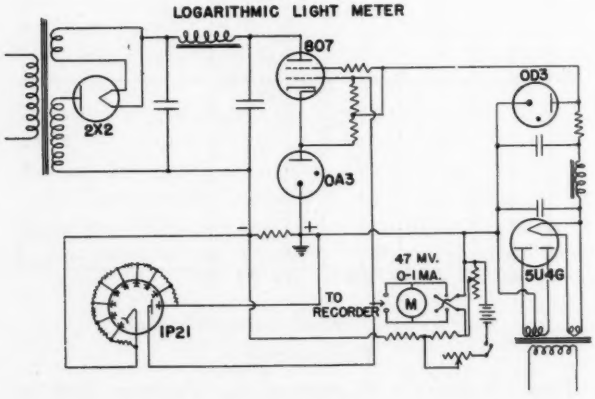
FORWARD-SCATTERING SMOKE PHOTOMETER




a 6 volt, 5 ampere light bulb, B. Two 2-1/2 in. diameter, 2-1/4 in. focal length aspheric condenser lenses, L, form an intense image of the source at the center of the smoke tube. The convergent illuminating beam passes through a small aperture, A, in a thin diaphragm (perpendicular to the plane of the figure) supported in slots in the center of the smoke tube. The center of the illuminating cone is blocked out by a 1 in. diameter disc, D, of black velvet. A circular screen, S, (perpendicular to the plane of the figure) serves, together with the thin diaphragm, to prevent stray light from reaching the phototube. The side of the screen away from the source and the end of the chamber upon which the divergent illuminating beam falls are covered with black velvet to further reduce stray light.

FIG. 6

LOGARITHMIC LIGHT METER




The collecting lens, 1, is located just within the cone of darkness formed by the disc, D. The collecting lens forms an image of the aperture, A, and the illuminated smoke in the plane of the phototube window, W. The size of this image is such that the faintly illuminated edge of the aperture falls outside the window and does not reach the phototube. The light scattered from the smoke reaches the collecting lens at angles, $\theta$, of 4° to 36° to the limiting rays of the divergent illuminating beam. As described above, these angles include much of the scattered light of highest intensity. Not all of the light scattered within these angles falls on the collecting lens, but the observed scattered intensity is very high. The dust in ordinary room air appears brilliantly illuminated when observed through an eye lens located at the window, W. This method is similar to that used by the author [12] for laboratory measurement of mass concentration, and by Gucker [13] and associates for counting of individual smoke particles.

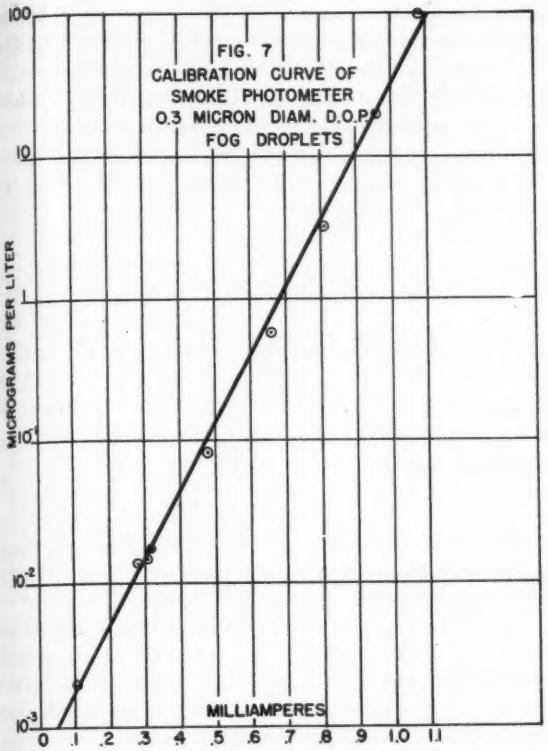
As shown in Table I, the possible range of turbidity in atmospheric aerosols is very great—$10^6$ or more. However, such a wide range would be unusual. Small particles usually occur at the higher concentrations, and $10^7$ ten micron diameter water droplets per liter corresponds to a very dense fog of 5 grams per cubic meter.

Nevertheless, the range may be expected to be at least $10^5$. In order to attain this range on a recorder chart without adjustment of the sensitivity, a logarithmic amplifier was designed for use with the photomultiplier tube by Mr. William Vissers of this laboratory. Figure 6 shows a schematic diagram of the amplifier and phototube.

This logarithmic light meter operates on the principle that the anode current of the phototube controls the plate resistance of an 807 tube which is effectively in series with the high voltage supply of the phototube. An increase in scattered light increases the anode current which increases the grid bias on the 807 control tube. This, in turn, increases the plate resistance of the control tube, which decreases the voltage applied to the phototube.

This condition of operation insures that the phototube operates at its maximum sensitivity for low light levels. Appropriate voltage bucking circuits are included to give full scale response for a predetermined amount of scattered light. The change in scattered light intensity is proportional to the change in phototube voltage. The latter was measured by measuring the photo-current with a 0-1 milliammeter of 47 ohms resistance. It may also be measured with a recording potentiometer.

Laboratory tests of the complete instrument showed that a reading of full scale on the meter corresponds to a range of $10^5$ in smoke concentration. Figure 7 shows the results obtained on dioctyl phthalate fog of 0.3 micron diameter (refractive index 1.48, density 0.975). The abscissas are the meter reading in milliamperes and the ordinates are the mass concentration in micrograms per liter (milligrams per cubic meter). The useful turbidity range of the instrument as presently constructed is from about $2 \times 10^{-6}$ per meter to 0.2 per meter, corresponding to a visual range of 2000 kilometers to 20 meters. Table I shows that the lower limit corresponds to $6 \times 10^4$ drops per liter for 0.3 micron diameter water drops, 650 drops per liter for 1 micron drops, or 13 drops per liter for 10 micron drops. The upper limit is higher than the turbidity of any atmospheric aerosols except dense water fogs.




The reading of this instrument will not be exactly proportional to the concentration of atmospheric aerosols, for several reasons: (1) Variations in particle size and type may occur. However, if in a given locality such variations are relatively small, the readings will record the changes in concentration during the intended 24 hour period of operation. (2) The illumination is by white light, equivalent to the measurement of a range of particle sizes equal to the range of wavelengths. The result is to smooth out the variations in the intensity distribution and total scattering, in addition to the smoothing caused by the range of particle sizes in a given atmospheric aerosol. Consequently, a moderate change in average particle size or in size distribution does not have a marked effect on the scattering. (3) The proportion of the total scattered light that falls within the angular range of 4° to 36° varies with particle size. This would require a correction similar to that applied to transmission measurements. However, the smoothing just referred to reduces the effect of this variation on the observed scattering. (4) The instrument does not measure the total turbidity of absorbing particles, but only the scattering by such particles. For highly absorbing particles, the scattering coefficient may be one-half the extinction coefficient or even less. (3, 7)

For the above reasons the instrument should be, in effect, calibrated with the atmospheric aerosols found in a given locality. For this purpose it is planned to collect on a filter all the smoke passing through the instrument during each test period. (C.W.S. No. 6 paper should be suitable.) The amount collected may then be weighed and correlated with the readings of the instrument. In addition, the deposit may be examined visually to determine its color, or microscopically if more quantitative information is desired. It is also planned to install an impinger ahead of the smoke tube inlet to remove particles greater than about 10 microns diameter. Such large particles are few in number, they produce large erratic readings and may become deposited in the smoke tube.

The instrument is constructed so that the scattered light readings may be compared with the intensity of the light source. This is done by rotating the phototube housing about an eccentric axis on the smoke chamber until the window, W, is in line with the opening, O. This opening is covered with a dense, gray filter on which some of the direct rays from the light fall. The light transmitted and scattered by this filter provides a standard comparison source. The light should be operated by a regulated transformer slightly below rated voltage to prolong its life.

It is appreciated that this instrument does not provide data for determining particle size and size distribution, etc. To obtain such data, even when possible, requires so much information that the labor of analyzing it is almost insurmountable. It is felt that a qualitative, but continuous record of the hourly and daily variation of visibility is more suited to the ultimate purpose, the reduction of air pollution, which is qualitative at best.

It is a pleasure to acknowledge the assistance of Messrs. W. Gulick, J. C. Betz and G. Nelson in construction of apparatus.

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# Methods of Education for Air Pollution Control

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Air Pollution Control as it relates to those of us in the Railroad Industry is primarily the controlling of the emission of excessive smoke by steam locomotives; however, there is also a problem in air pollution presented by the currently popular and very efficient diesel locomotive. However, as this side of the air pollution picture is largely one of maintenance and can not be controlled by the engine crew I will endeavor to deal only with the methods of education pertaining to the engine crew of the steam locomotive.

The first and one of the most important functions in the education of employes in the control of air pollution is to employ only those men for service as Firemen who are of good moral character, have at least a high school education and are willing to study and apply themselves.

The Employment Officer should try to determine whether the applicant is considering railroading as his career, or whether he is only looking for a temporary job.

After passing the necessary physical examination he is given a Time Table and receives a thorough course of instruction by the Road Foreman in connection with the duties and responsibilities of his new job.

In addition, each new employee, regardless of his craft assignment, is required to spend a full eight hour day in our Central Training Center, located at Reading, Pa., where he is instructed by competent full-time instructors in Railroad practice generally and safety in his new job in particular. Here he is furnished with a copy of the System Safety and Operating Rules, together with a book containing our standard progressive examination for locomotive Firemen for promotion to Enginemen, which book covers first, second and third year examinations in both steam and diesel power, as well as air brakes, which he must pass within three years after being employed to be eligible for promotion to the position of Engineman.

Each Fireman is also provided with a Manual entitled, "Firing the Steam Locomotive," which covers in its entirety the duties of the Fireman assigned to a steam locomotive together with descriptions of the generally accepted practices which have over the years proven to be most successful.

The Manual referred to covering, among other things: safety, crew cooperation, the fireman's duties, smoke and draft control, coal, combustion, the stoker, the grates, the boiler, locomotive water systems, the superheater and fire conditions. This latter heading includes how to prepare a fire, how to inspect the fire, firing of different coals, conditions that affect the fire and how to correct bad fire conditions.

After receiving instructions at the Training Center the task of further instructing and supervising the work of the Fireman becomes the responsibility of the Road Foreman and his Assistants, who give each new Fireman primary instructions on the construction of the locomotive, stressing the construction of the boiler, firebox, grates, arch and units, as well as all other draft appliances.

The student Fireman is then required to make two trips or days with an experienced Fireman, selected by the Road Foreman, known to possess the ability to impart his knowledge to the student. Such instruction to cover all phases of the locomotive Fireman's duties in preparing the locomotive for the trip and proper methods of firing with both shovel and stoker on line-of-road, with particular emphasis on how to fire the locomotive to maintain maximum steam pressure at all times with the minimum of smoke.

Hostlers, fire cleaners and water tenders are also instructed in generally the same fashion by experienced employees in these crafts, although they are not required to maintain maximum steam pressure, but rather instead are required to build and maintain fires at the engine house with a minimum of smoke. To accomplish this, when building fires, the employee must first be smoke conscious and take a certain amount of pride in doing his job with the least amount of smoke, generally using the horse shoe bank method while building and main-

taining the fire which has been proven to be the most successful method for use at Terminals in the controlling of the emission of smoke.

In my opinion, the most important factor in the control of air pollution by the locomotive crew, assuming that the locomotive is correct mechanically, is cooperation between the Engineman and the Fireman. Without this, the best Fireman cannot do a good job in the controlling of the emission of smoke; likewise, the best Engineman cannot be expected to do a good job in hauling his train over the Division on time without the complete cooperation of the Fireman.

The word cooperation is too big and meaningful to be completely defined and although every crew recognizes the importance of cooperation; nevertheless, every once in a while someone violates that principal.

Lack of cooperation makes the job tougher for everyone concerned. The usual result is, as everyone knows, trouble and sometimes even failure.

This is true in every line of work whenever a group is involved and particularly so on the Railroad Locomotive where lack of cooperation will most definitely result in failure, or at the very least, in an inefficient, wholly unsatisfactory performance.

In placing cooperation at the head of the list, I am not unmindful of the numerous other important related duties in which the Fireman must be instructed and constantly be supervised in order to do a good job in the elimination of smoke.

To obtain the best results, the Fireman must actually burn the coal furnished to decide what method to use to produce the required steam pressure economically and with a minimum of smoke.

It cannot be determined by looking at the coal how it will burn in the locomotive; however, there are general observations that can be made which will assist in obtaining the greatest efficiency from the coal with a minimum of smoke, some of which are:

1—Observe whether the coal is lump, slack or run-of-mine, also its texture.

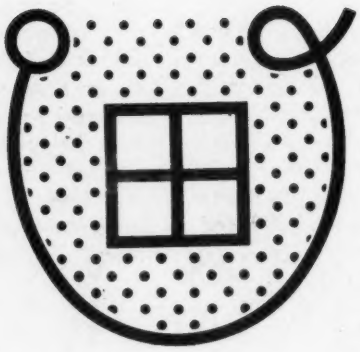
2—Observe whether it is wet or dry.

3—Check the coal frequently as it enters the stoker trough for foreign matter.

4—Only operate stoker fast enough to furnish coal to the fire as it is burned.

5—Do not open the fire door unnecessarily.

6—Use blowers as lightly as possible and no longer than necessary.

7—Stop firing far enough in advance of a stop or Terminal to insure that all smoke and gases will be consumed before the throttle is closed and apply blower before Engineman closes throttle.

In conclusion, I might state to those of us who still have the air pollution or smoke problem to deal with in steam locomotives. We have made great strides in the elimination of smoke over the years; however, we cannot afford to sit back and rest on our laurels. We must advance or we will find ourselves moving backwards, therefore, it is of utmost importance that the men who choose to enter upon a Railroad Career and start in by firing locomotives, should be thoroughly trained and familiar with their responsibilities, duties and the equipment they will have to handle. Therefore, I repeat, the most important factor in the control of air pollution by the elimininations of smoke is cooperation on the part of the engine crew.